Jet Propulsion Laboratory
California Institute of Technology

Hardy Tree-Mounted Loop Antenna for the Tree of Life Mission

ISSC 2022, California Polytechnic State University, May 3rd, 2022

Charles Penny, Alessandra Babuscia*, Steven Anderson, Julia Christensen**, Steve Matousek*, Roger Klemm*,*

* Jet Propulsion Laboratory, California Institute of Technology; **Oberlin College

Outline

- Motivation
- Project Background
- Objectives
- Prior Research
- Methods
- Some Results
- Changes
- More Methods
- More Results
- Discussion/Moving Forward

Proxima Centauri – Image taken by the Hubble Space Telescope

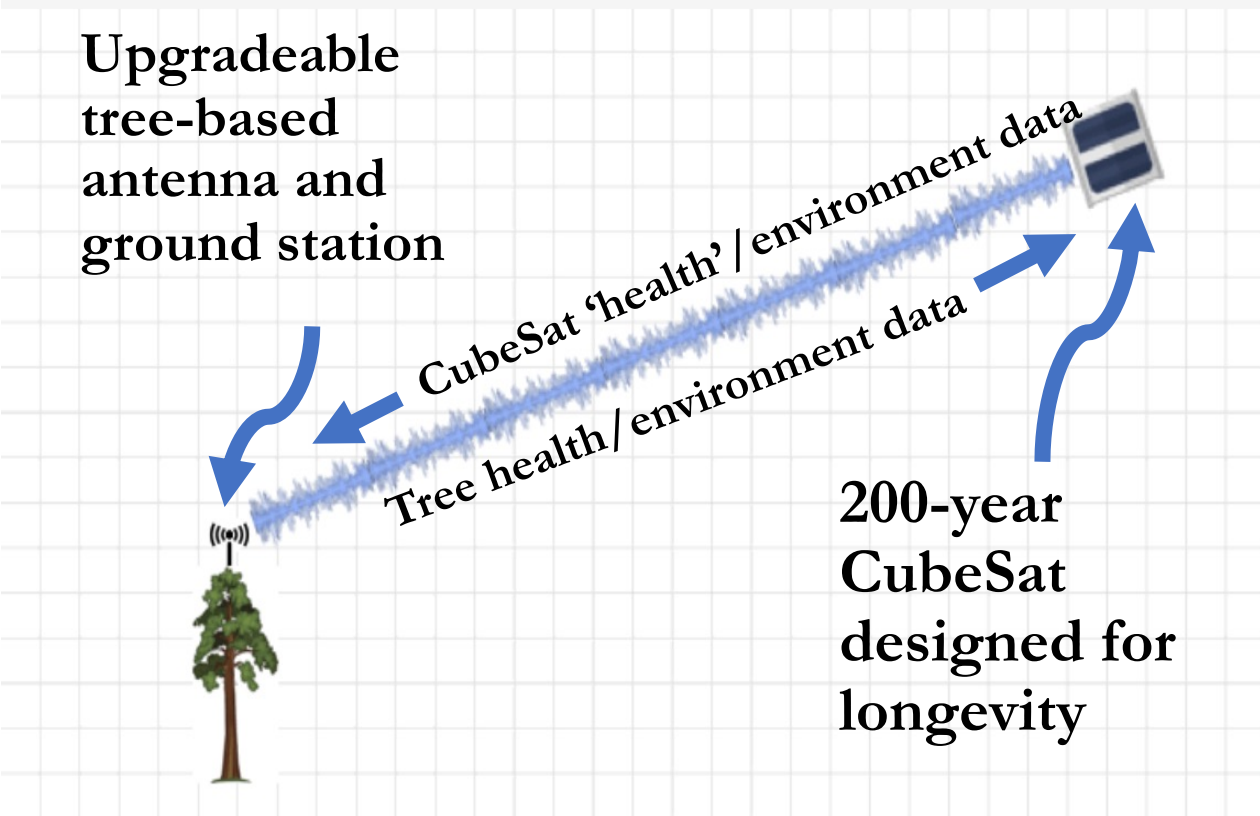
Motivation (1/2)

The Tree of Life Mission:

- Interstellar missions may last 200+ years
- How do we design craft to last for such durations?
- How do we design ***missions*** to last for such durations?

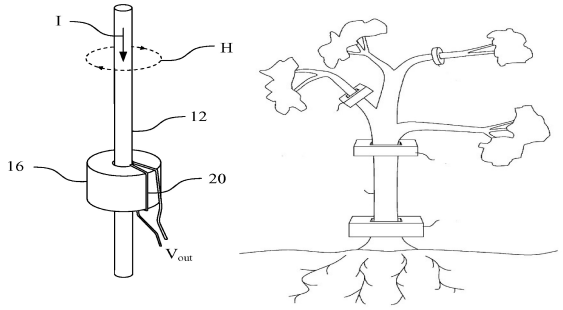
Motivation (2/2)

- Combine space and Earth science missions of similar duration
  - Diversify sources of interest
  - Crowdsource ground station upkeep
- Trees can have long lifespans
  - Trees became focus of Earth science

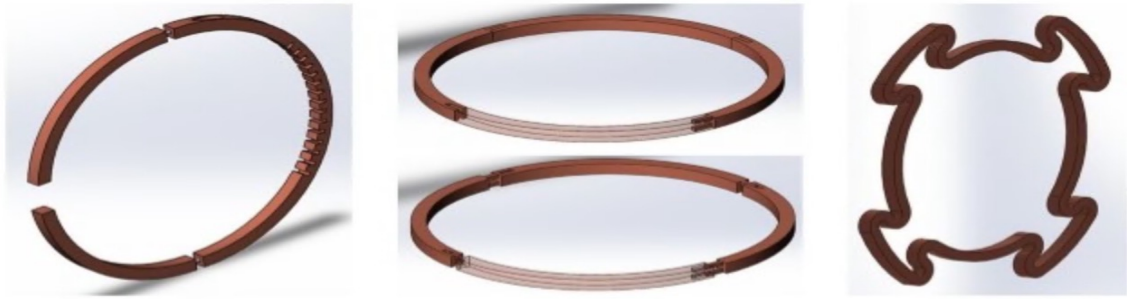


Credit: Space Song Foundation

Project Background – Tree Antenna



Daniel Tam and John Rockway - US Patent No. 8,094,083



Steven Anderson – Tree of Life Antenna concepts (2020)

CON – Trees are somewhat unpredictable regarding location, shape, etc.

CON – Trees exhibit non-constant electrical and physical properties

PRO – Antenna has close proximity to data collection station and high mounting location

PRO – Tree-Antenna system has somewhat improved beamwidth for an uncomplicated antenna

Objectives

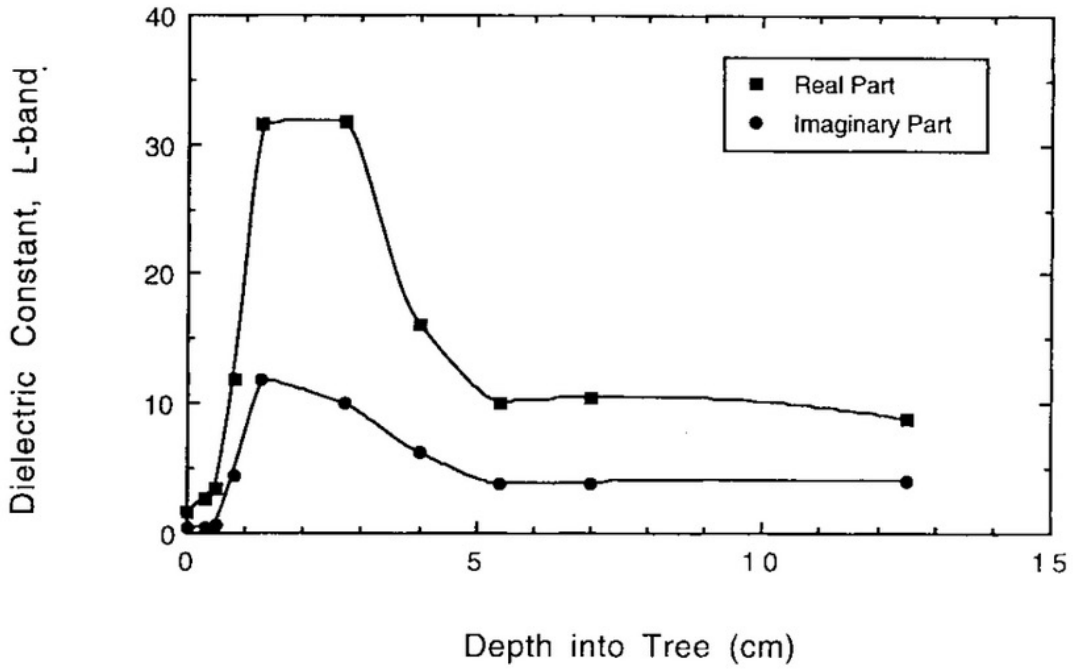
Design antenna that is hardy to an on-tree environment

To do this we must

1. Understand typical tree conditions
   - namely electrical properties

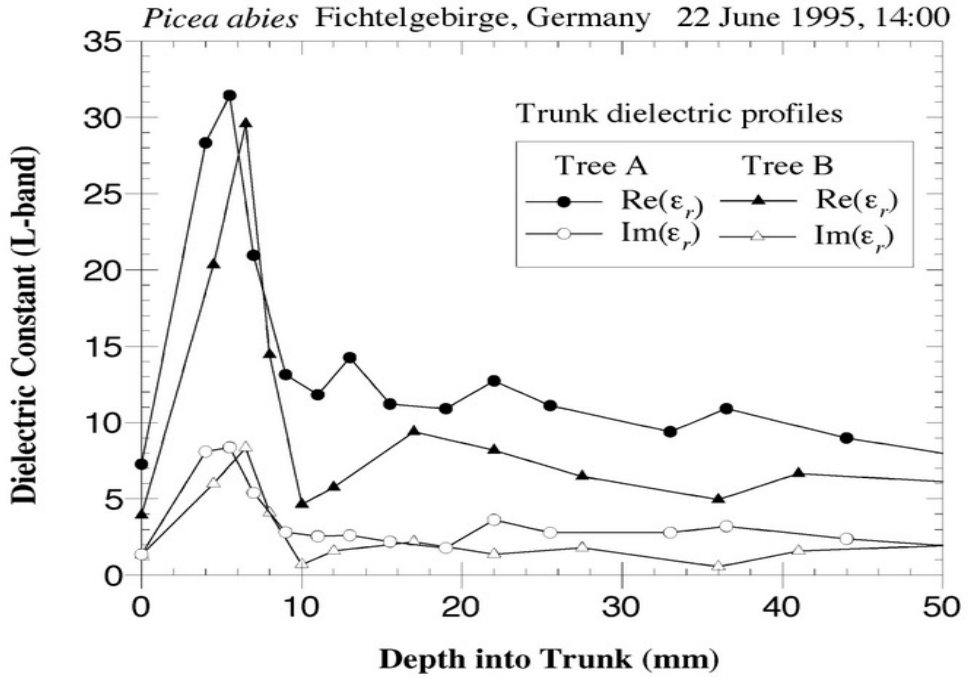
2. Characterize antenna performance in typical conditions

Prior Research (1/2)



Automated Instrumentation for Continuous Monitoring of the Dielectric Properties of Woody Vegetation: System Design, Implementation, and Selected In Situ Measurements

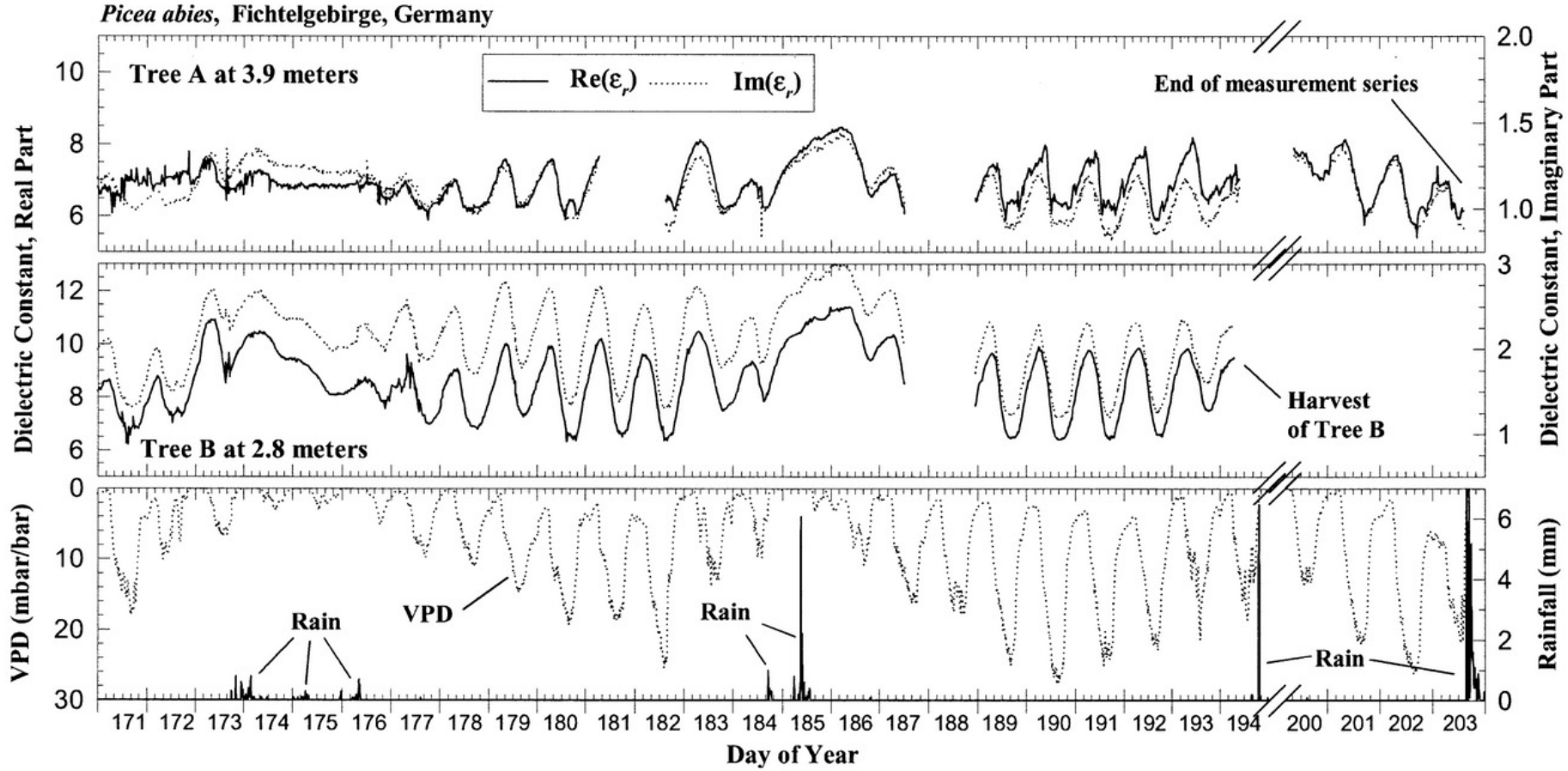
Kyle C. McDonald, Reiner Zimmermann, JoBea Way, William Chun



Diurnal and Spatial Variation of Xylem Dielectric Constant in Norway Spruce (Picea abies [L.] Karst.) as Related to Microclimate, Xylem Sap Flow, and Xylem Chemistry

Kyle C. McDonald, Reiner Zimmermann, and John S. Kimball

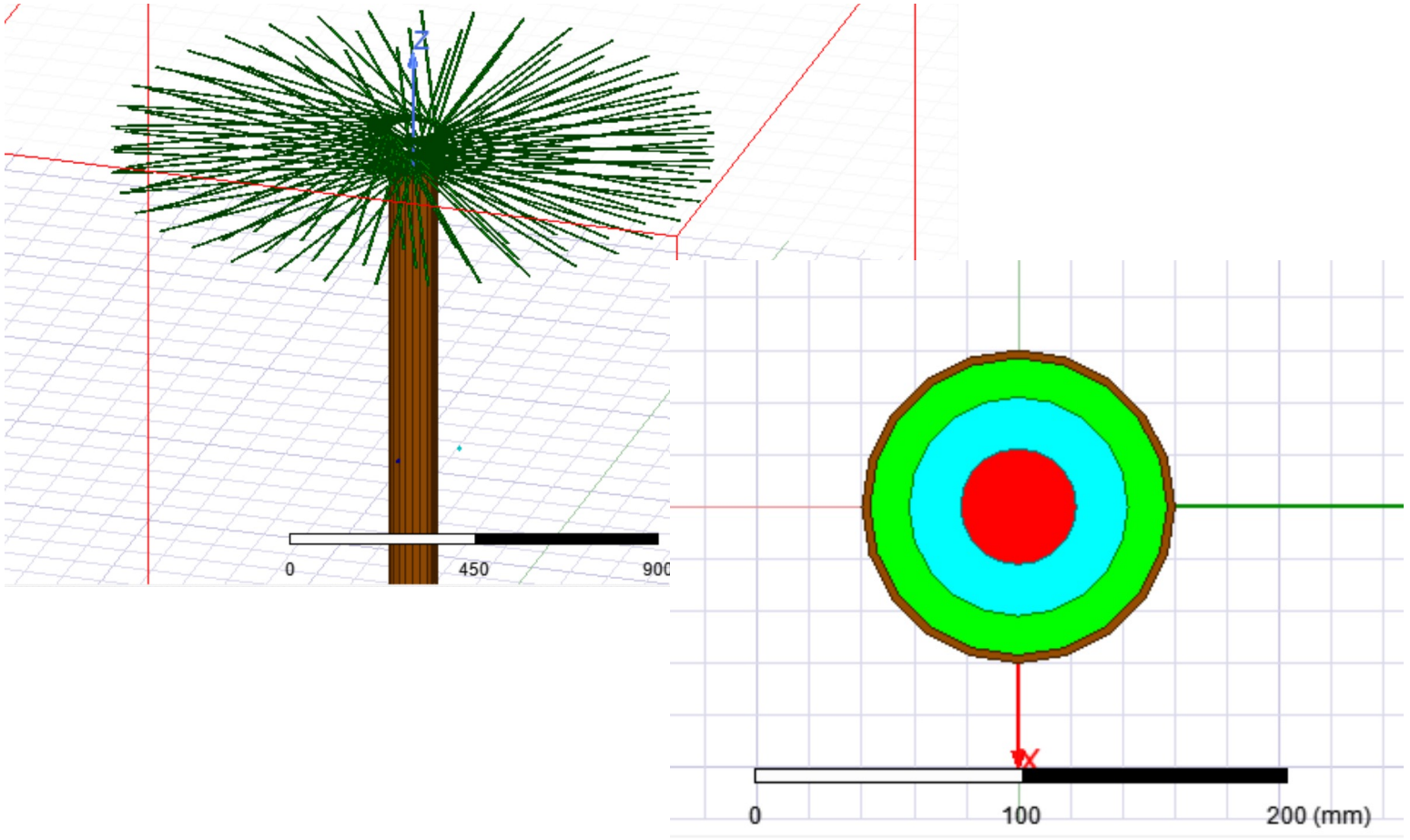
Prior Research (2/2)



Diurnal and Spatial Variation of Xylem Dielectric Constant in Norway Spruce (Picea abies [L.] Karst.) as Related to Microclimate, Xylem Sap Flow, and Xylem Chemistry

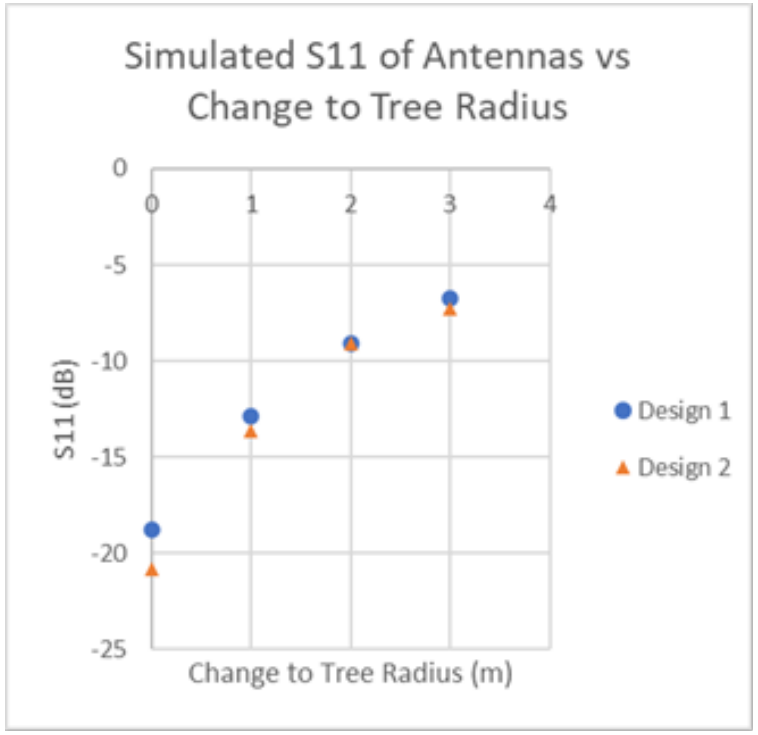
Kyle C. McDonald, Reiner Zimmermann, and John S. Kimball

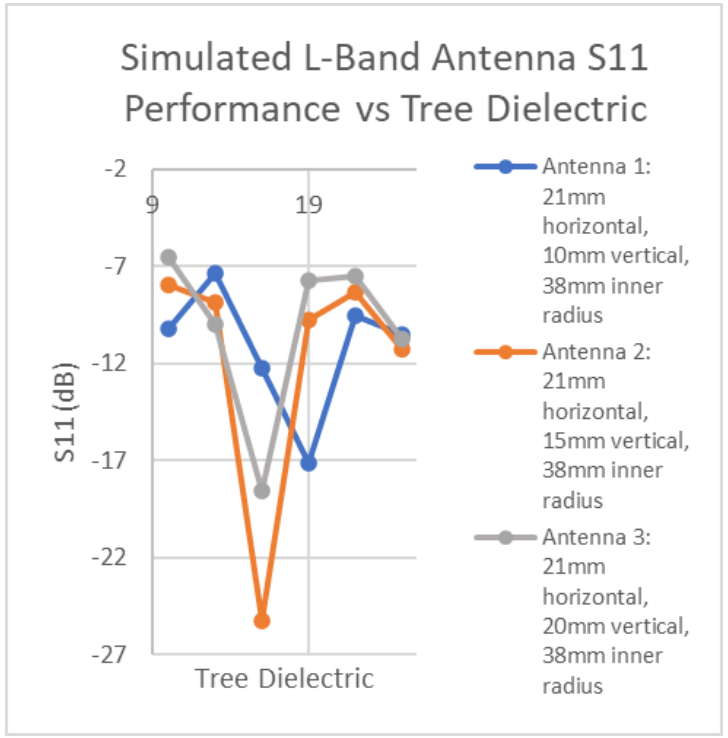
Methods - Simulation



Ansys HFSS models aiming to represent different layers of tree tissue and foliage

Some Results – Antenna Sensitivity to Tree Properties



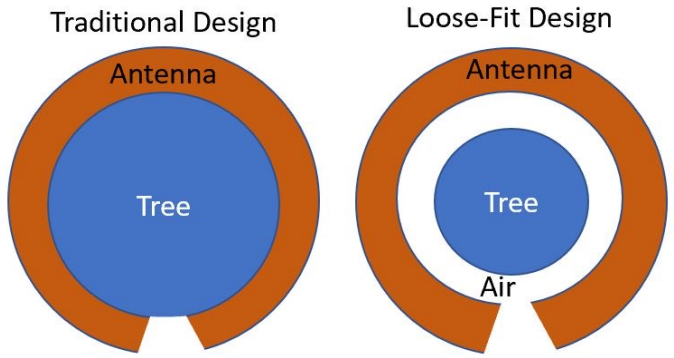


- Changing dielectric results in shifting resonant frequency
- Deformation due to gradual tree growth ruins antenna

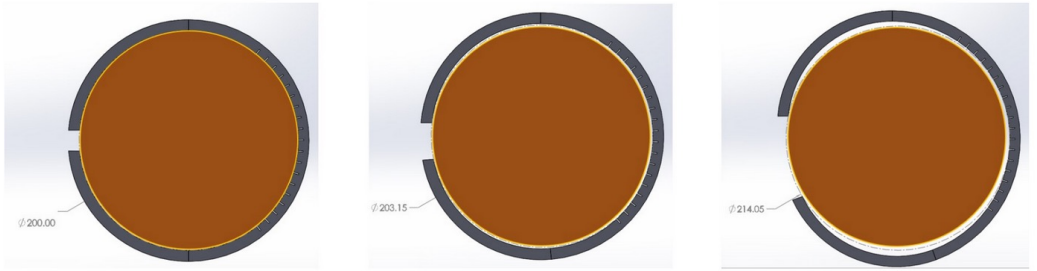
Antenna is very sensitive to tree's changes!

Minimizing Impact

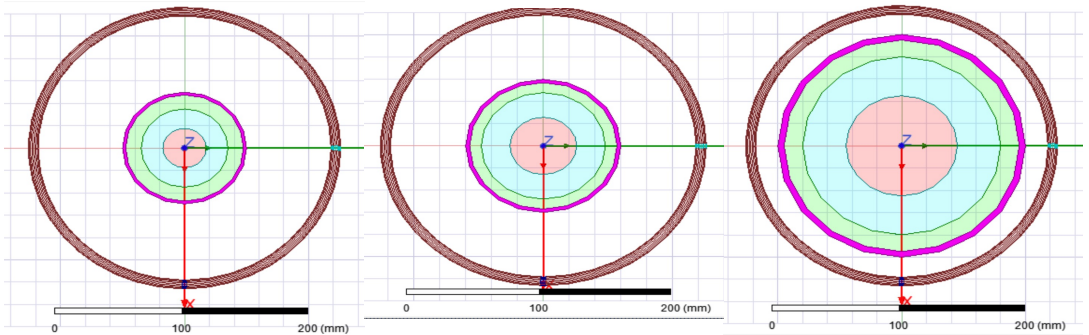
Decrease volume of tree enclosed by loop antenna



Decrease deformation caused by tree growth

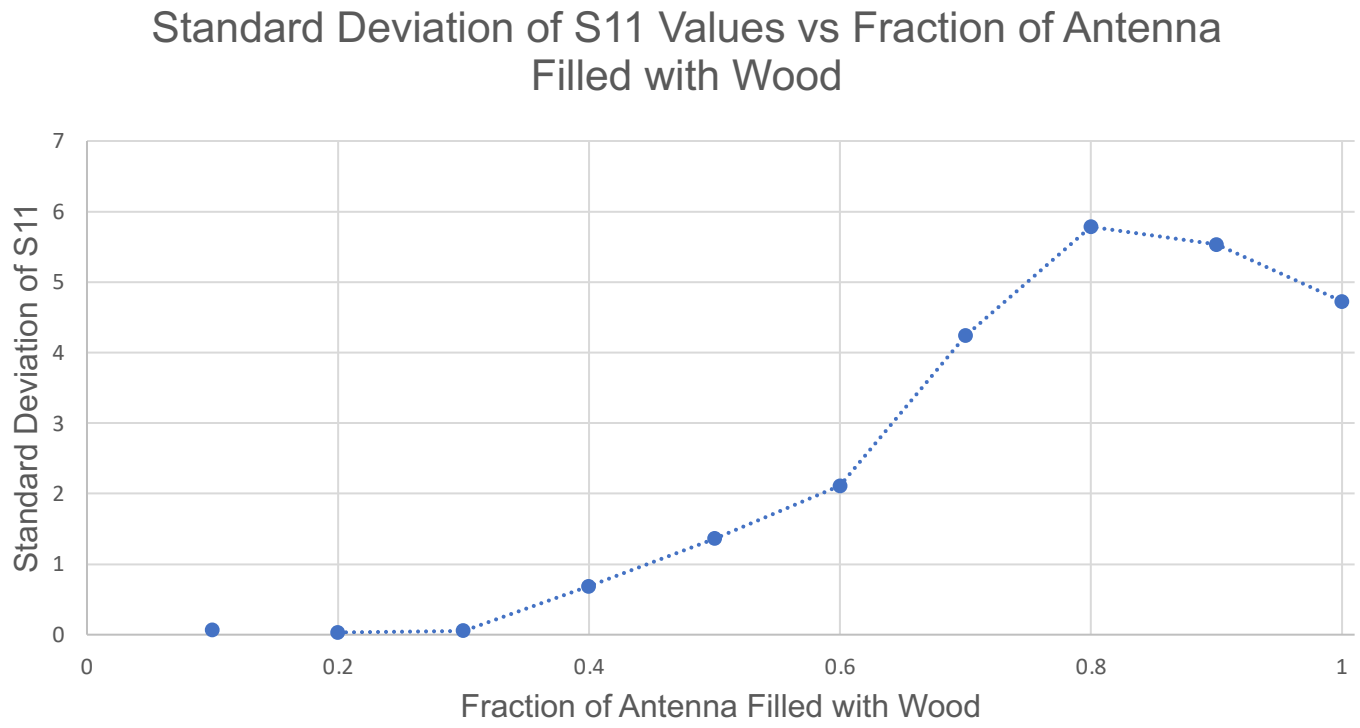


Simulate design in HFSS for varied conditions



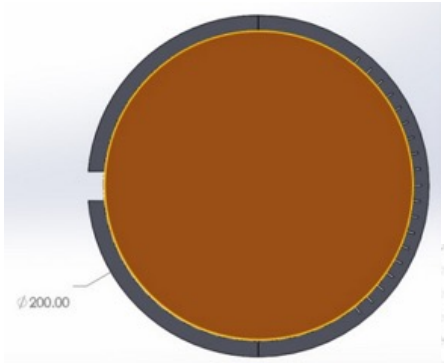
Impact Minimization

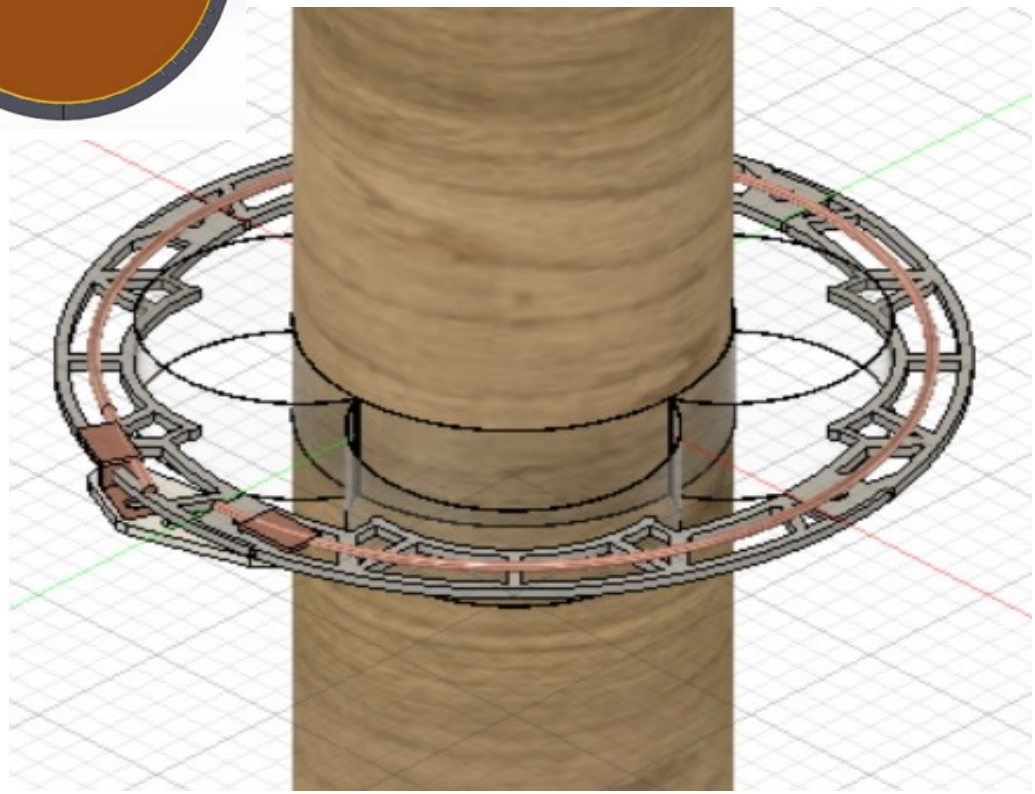
- Simulation sweeps of tree dielectric values for varying tree area show *more consistent* antenna performance for smaller tree areas



Design Changes

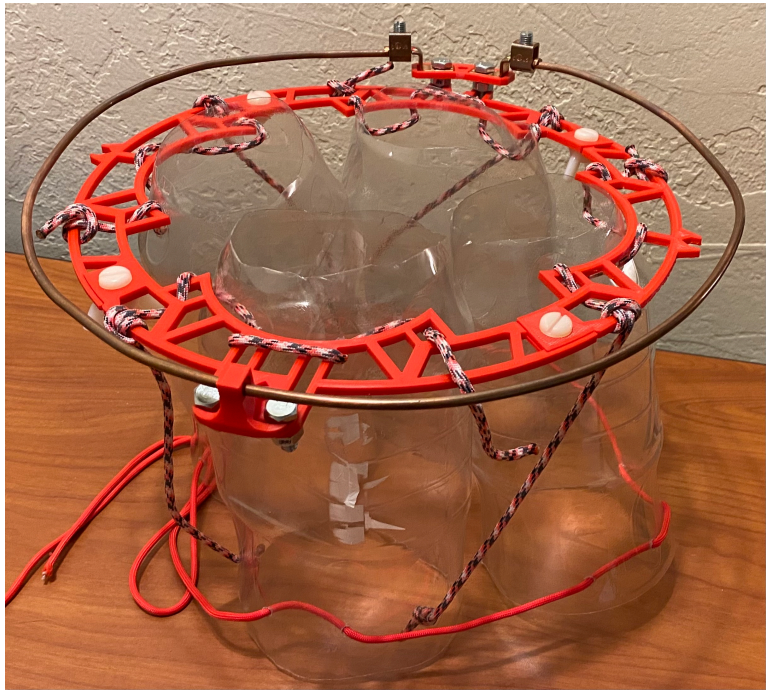
- Reduces tree branch size enclosed
- Spring absorbs deformation instead of antenna
- Wider range of fitting branches due to spring mount





How do we know our simulations are any good?

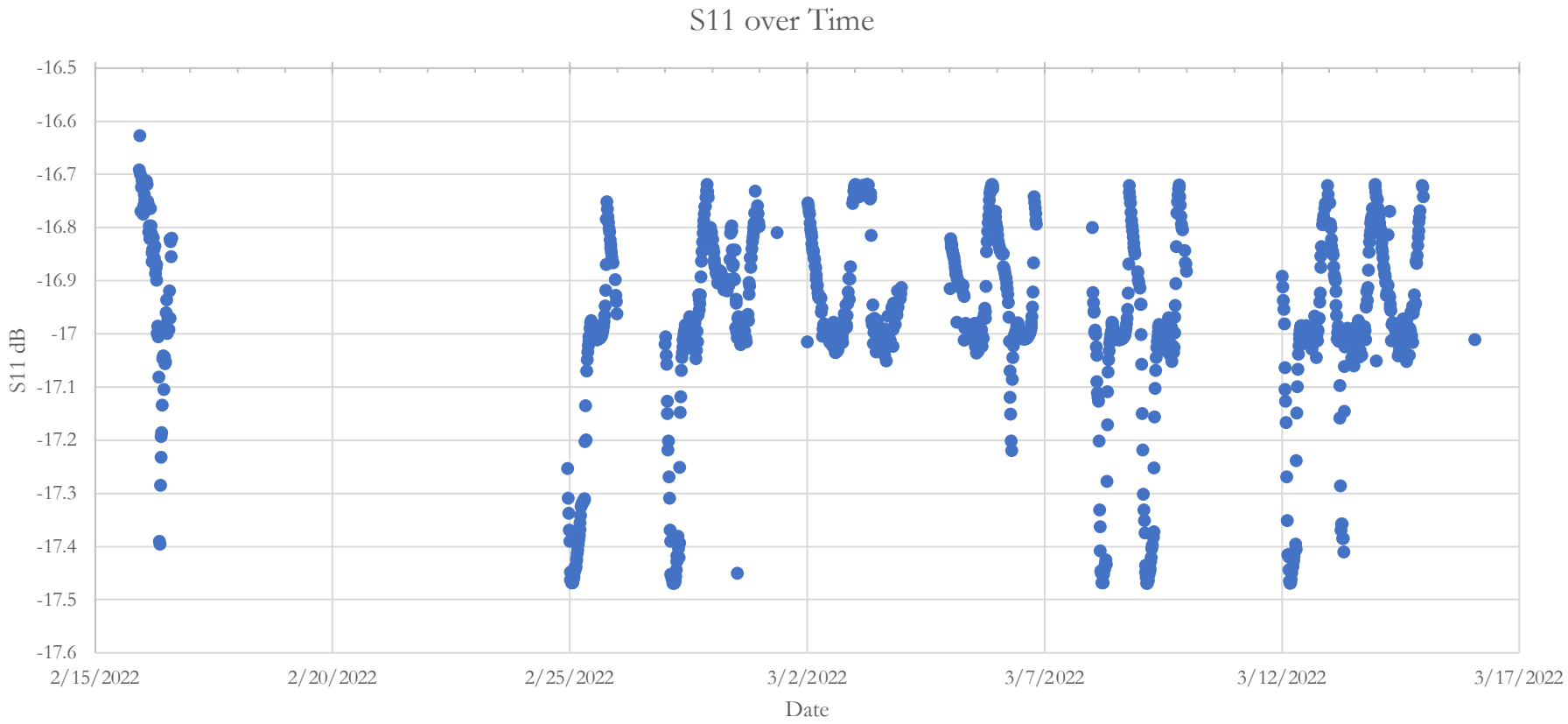
Testing!



More Methods – Testing in Typical Conditions

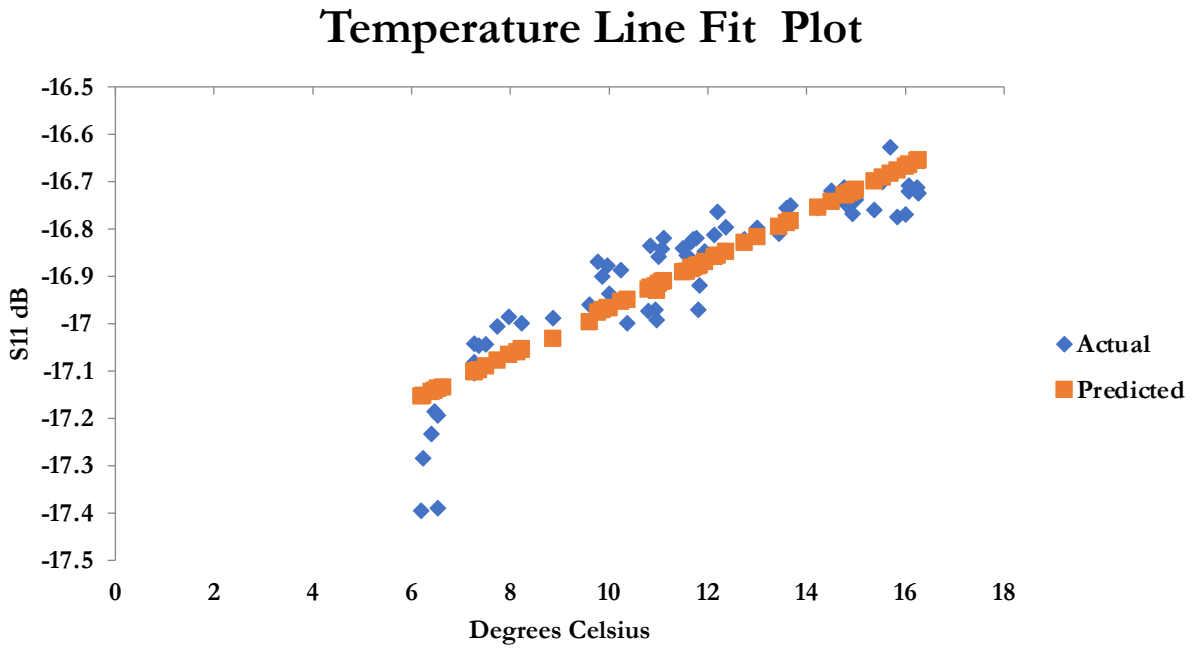
- How will the Antenna react to real life dielectric shifts?
- Is our simulation model accurate?
- Antenna on tree, VNA, raspberry pi, battery, and solar panel in bucket

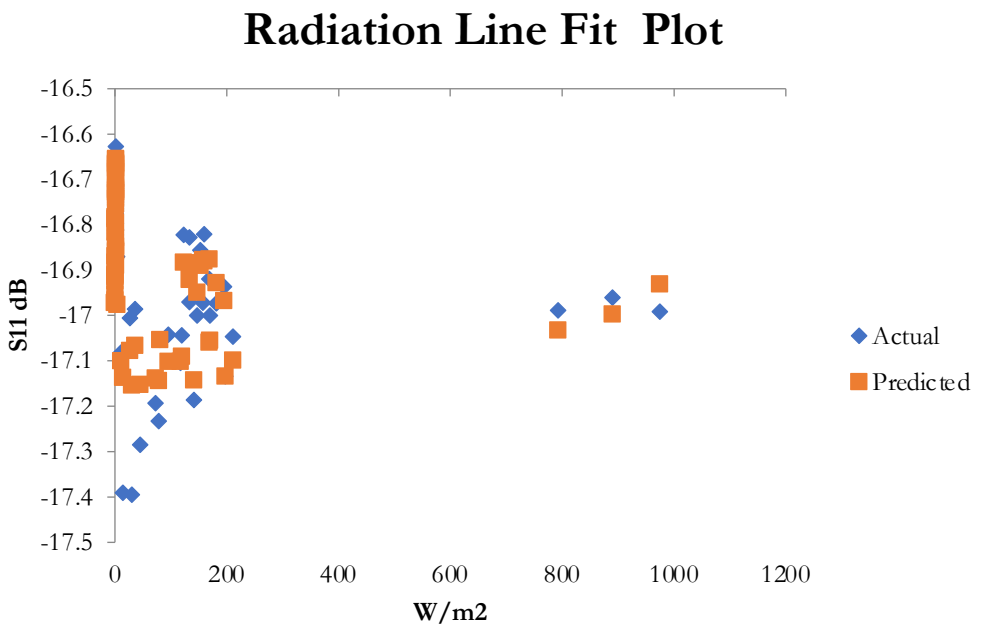
Typical Conditions Results/Analysis



Antenna Performance vs Environmental Factors

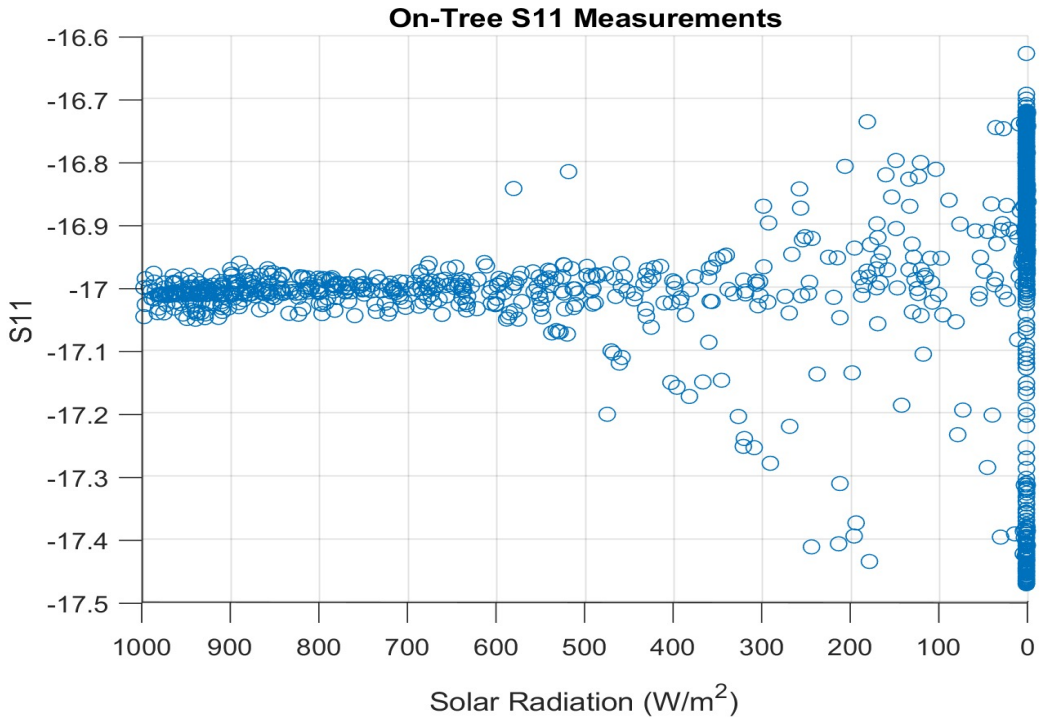
- Data generally showed high correlation to ambient temperature and solar radiation

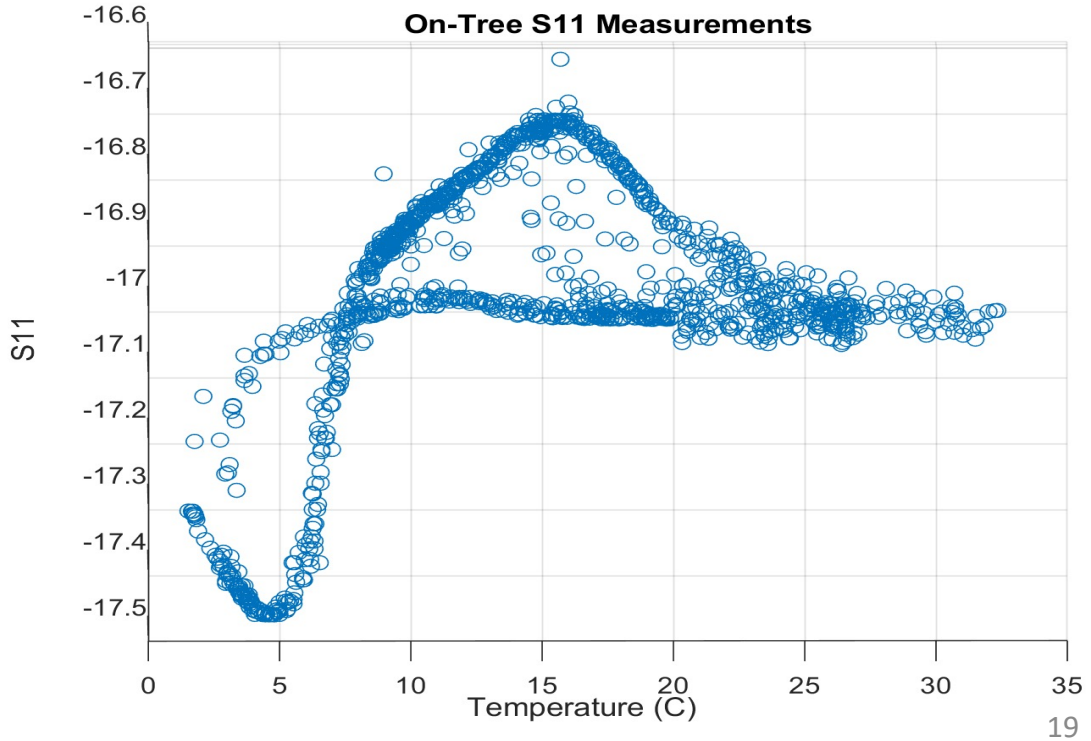


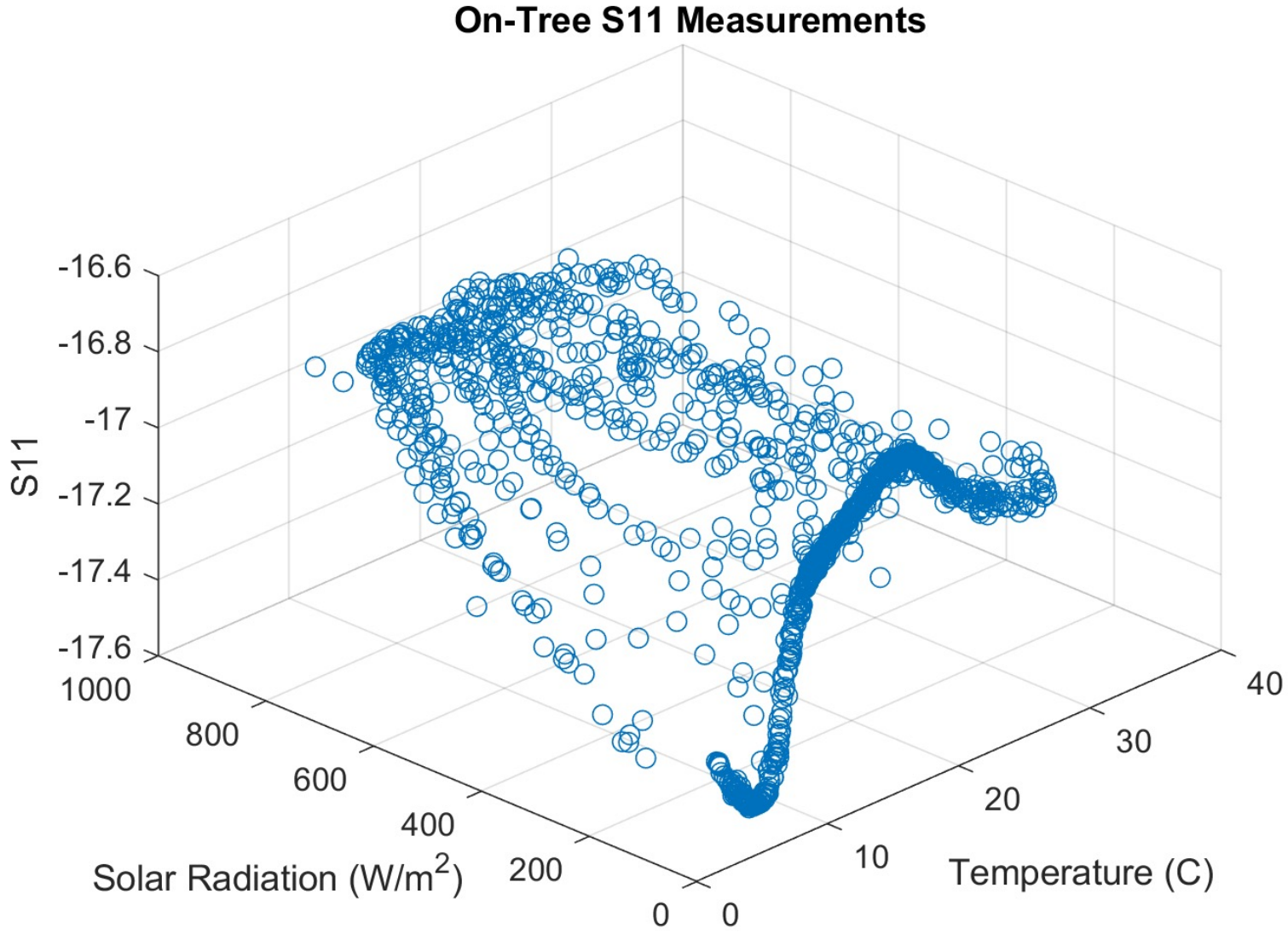


Antenna Performance vs Environmental Factors

- Antenna performance seems to be powerful indication of tree's environment





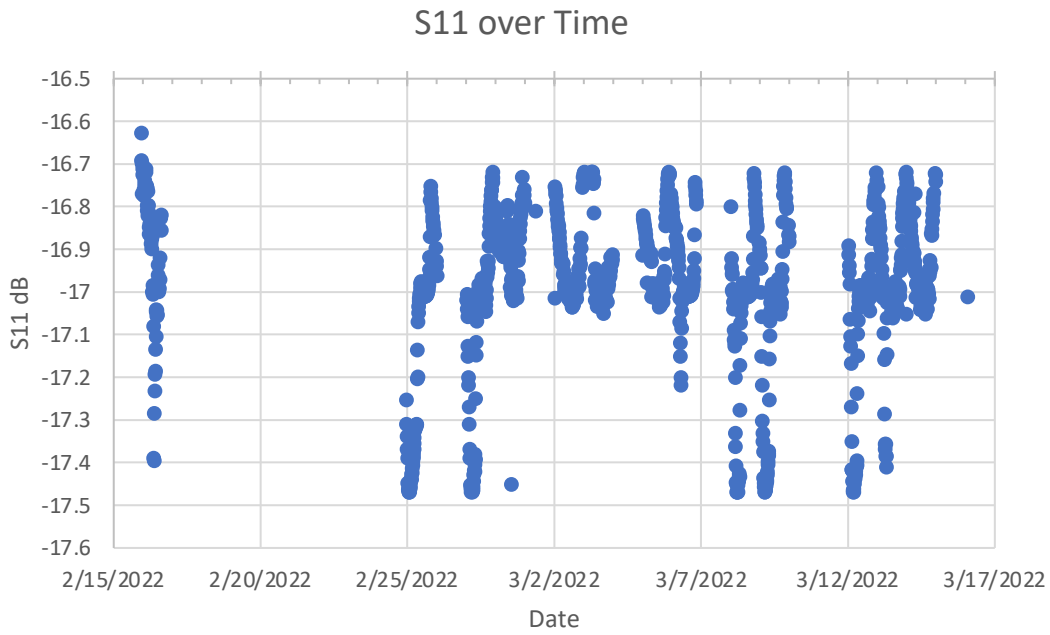

On-Tree S11 Measurements
S11
-16.6
-16.8
-17
-17.2
-17.4
-17.6
Solar Radiation (W/m2)
1000
800
600
400
200
0
Temperature (C)
0
10
20
30
40

Discussion

- Antenna design changes successfully minimize effect of tree activity on antenna performance

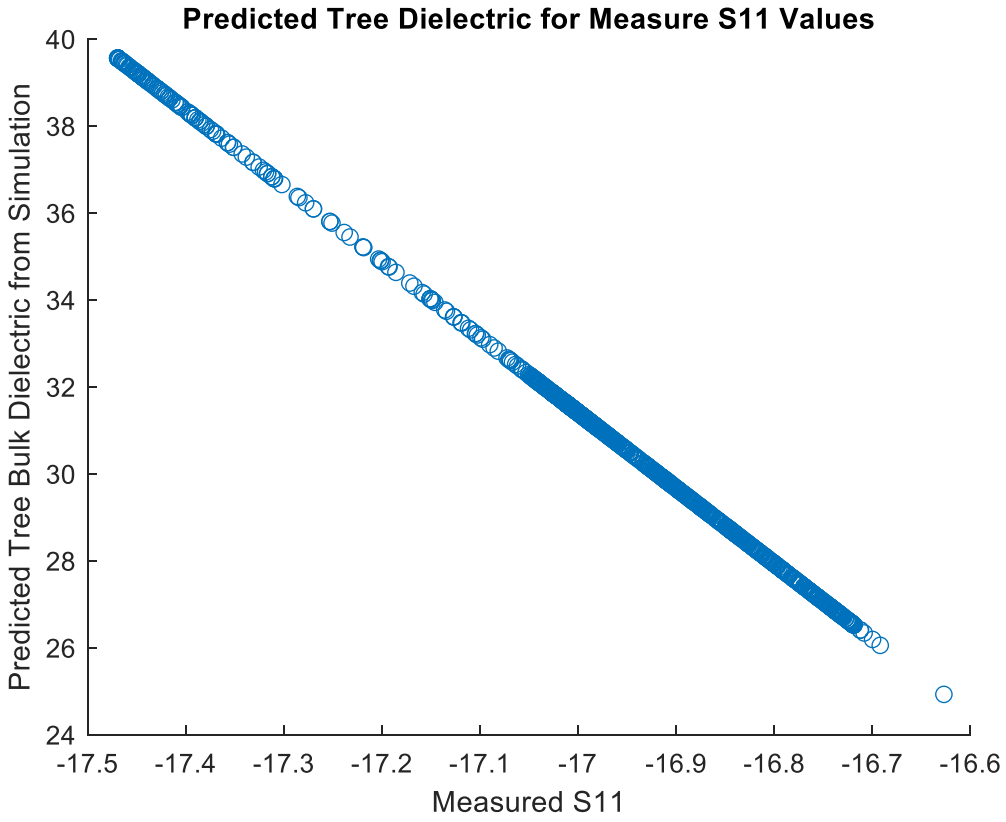
  -antenna is also generally less sensitive than in simulation

- Antenna performance still reflects tree activity



Moving Forward

- A Tree-Antenna as a Tree-Transducer?
- Further development of the system
  - Multi-branch array
  - Multi-tree array
  - Testing against 'open-source' 433MHz satellites



Acknowledgements

Thanks to Alessandra Babuscia for her mentorship!

Thanks to all the former interns who worked on this and whose work laid the foundation for everything I have done!

Inge Baho - Thomas Choi - Steven Anderson

Thanks to Dr. Kyle McDonald for insight into the dynamic properties of trees!

Thanks to The Tree Song Foundation for involving me!

Thanks to Dr. Jekan Thanga and SpaceTREx Labs for supporting this research!

Jet Propulsion Laboratory
California Institute of Technology

Thank you!

for your time

References

- https://www.spacesong.org/
- Q. Xiao and E. G. McPherson, "Tree health mapping with multispectral remote sensing data at UC Davis, California," *Urban Ecosystems*, vol. 8, no. 3-4, pp. 349–361, 2005. https://link.springer.com/article/10.1007/s11252-005-4867-7
- M. Acker, K. Ikrath, and W. A. Schneider, "HELICAL COIL COUPLED TO A LIVE TREE TO PROVIDE A RADATING ANTENNA," 29-Feb-1972. https://patentimages.storage.googleapis.com/31/f8/8b/e11a188592e001/US3646562.pdf
- D. W. S. Tam and J. W. Rockway, "MULTI-BAND TREE ANTENNA," 10-Jan-2012. https://patentimages.storage.googleapis.com/19/cf/0f/424d5e0be1614f/US8094083.pdf
- I. Baho, rep. "Tree of Life: Designing and Simulating the Antenna Tree," 2019.
- T. Choi, rep. "Tree Antenna Report," 2020.
- S. Anderson, rep. "Tree of Life: A Multi-Generational Telecommunication Concept", 2021.
- K. C. McDonald, R. Zimmermann, J. Way, and W. Chun, "Automated instrumentation for continuous monitoring of the dielectric properties of woody vegetation: System design, implementation, and selected in Situ Measurements," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 37, no. 4, pp. 1880–1894, 1999.
- K. C. McDonald, R. Zimmermann, and J. S. Kimball, "Diurnal and spatial variation of xylem dielectric constant in Norway spruce (picea abies [l.] karst.) as related to microclimate, xylem sap flow, and xylem chemistry," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 40, no. 9, pp. 2063–2082, 2002.