

Dr. Sathyanarayan Rao

Research Scientist & Computational Engineer

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Education

- **PhD in Engineering Sciences**, UCLouvain, Belgium 2016 – 2020
Thesis: Computational Modeling of Electrical Signatures of Plant Roots
Awarded prestigious FNRS fellowship for doctoral research.
- **MS in Applied Physics**, Alabama A&M University, USA 2013 – 2014
GPA: 4.0/4.0
Conducted laboratory research in laser-matter interaction and photodegradation.
- **MS in Electrical Engineering**, University of Alabama in Huntsville, USA 2010 – 2012
GPA: 3.9/4.0
Research funded by NSF grant ATM0647157 on plasma simulation and modeling.
- **B.Eng in Electronics and Communication**, VTU, India 2006 – 2010
First Class with Distinction (77%, equivalent GPA: 3.9/4.0)
External project at Bharat Electronics Limited (BEL) in digital communication systems.

Experience

- **Research Associate**, Indian Institute of Science (IISc), Bengaluru April 2025 – Present
 - Designed and implemented **machine learning models (Random Forest, time-series analysis)** to improve SAR-based soil moisture estimation, achieving **34% accuracy gain** for sandy textures.
 - Analyzed **multi-year time-series data** (soil temperature and moisture at multiple depths) to uncover patterns in groundwater recharge, soil-water balance, and climate-driven disruptions.
 - Developed **automated pipelines in Python** for data cleaning, feature engineering, and statistical diagnostics (van Genuchten modeling, gradient analysis, recharge event detection).
 - Building **interactive dashboards** for visualizing soil-moisture-temperature dynamics, supporting both researchers and policymakers.
 - Submitted peer-reviewed findings on **soil-specific SAR calibration and machine learning frameworks**, contributing to operational remote sensing and hydrology communities.
- **Research Software Engineer**, Phenorob Project, Forschungszentrum Jülich 2023 – 2025
 - Developed robust interfaces to couple one-dimensional crop models (C/C++) with plant-scale Functional-Structural Plant Models (FSPMs; Fortran/CPlantBox), implementing loose-coupling data exchange, timestep synchronization and bidirectional parameter passing.
 - Created a python script for mechanistic sink-term for AgroC based on parallel root models enabling realistic root water uptake driven by dynamic root architecture (RLD) from CPlant-Box.
 - Built a cross-platform AgroC GUI using PyQt5 to generate and validate ‘plants.in’ input

files, including tabular editors, dynamic table sizing and robust save/load routines to support model runs and scenario testing.

- Packaged modelling tools and workflows with multiple Dockerfiles (AgroModeling stacks) enabling large-scale simulations on HPC clusters (batch scripts, container orchestration), improving reproducibility and scalability.
- Implemented project website and documentation (Hugo, SCSS, JavaScript) and created scientific visualizations/animations to communicate complex soil-plant processes to researchers and stakeholders.
- Led monthly project coordination, contributed to book chapters on LLMs and UAVs in agriculture, and authored a review on model coupling & digital-twin architectures (submitted to *In Silico Plants*).

● **Research Associate**, Indian Institute of Science, Bengaluru 2022 – 2023

- Transitioned from computational modeling to hands-on field research, leading bi-weekly campaigns in the Berambadi watershed and standardizing data formats from collection to analysis.
- Developed ML models (Random Forest, SVM, LSTM) for soil moisture prediction from SAR backscatter with ground-truth validation, co-presented poster at IIT Bombay Soil Moisture Workshop.
- Built preliminary data pipelines in Python for cleaning and block-wise extraction of soil measurements; automated dashboards using Vue.js, Plotly, and Leaflet for interactive visualization.
- Trained students in instrumentation and protocols, ensuring reproducibility and quality of time-series datasets.
- Created short educational videos on soil moisture retrieval methods, supporting outreach and team training.
- Explored computer vision methods for leaf area index (LAI) estimation from smartphone imagery; gained experience with image analysis workflows, though accuracy was limited compared to professional (LiCor).

● **Independent Research & Development Consultant** 2020 – 2022

- Returned to India during the COVID-19 pandemic while pursuing postdoctoral opportunities and academic grant proposals.
- Developed Python-based analytical tools for financial market analysis and algorithmic trading strategies using WebSocket APIs.
- Created machine learning pipelines for healthcare datasets and designed interactive UIs with frameworks such as Gradio.
- Applied time-series modeling and signal processing techniques across finance, healthcare, and environmental datasets.
- Demonstrated adaptability and resilience by maintaining active skill-building, and collaborations during the global disruption.

● **FNRS Research Fellow**, eRoot Project, UCLouvain, Belgium 2016 – 2020

- Developed **finite element models (FEM)** with up to 500,000 tetrahedral elements to simulate soil-root electrical interactions at anatomical and field scales.
- Integrated **root water uptake dynamics** and polarization effects into geoelectrical models, advancing non-invasive methods for root phenotyping.
- Quantified **electrical anisotropy signatures** of root systems and linked them to structural indices of root architecture.
- Applied **machine learning (k-nearest neighbors, PCA, statistical classifiers)** to discriminate root species from geophysical signatures.
- Built Python-based automation pipelines to generate and process thousands of 3D root

meshes (C-Rootbox + Gmsh) for simulation and validation studies.

- Deployed simulations on **HPC clusters** (FZ Jülich supercomputing facility) for large-scale computational experiments.

- Conducted field-scale Electrical Resistivity Tomography (ERT) experiments to phenotype root water uptake under drought stress, combining **numerical modeling with sensor data (ERT, TDR)**.

- Published peer-reviewed journal articles and delivered conference presentations on computational agrogeophysics and non-invasive plant imaging.

- **Research Assistant**

2010 – 2016

University of Paderborn, Germany

2015 – 2016

- Developed **FORTRAN-based numerical solvers** to simulate excitonic resonances in two-level systems for optical communication applications.

- Implemented **Maxwell–Bloch equations** using high-order Runge–Kutta, finite difference, and adaptive time-stepping for solution stability.

- Modeled photon–matter interactions in engineered two-level systems under **DFG-funded optical signal processing research**.

Alabama A&M University, USA

2013 – 2014

- Conducted experimental and theoretical research on **laser-induced photodegradation** of dye molecules (Rhodamine 6G).

- Performed **photo-patterning and photo-deposition** of biosensing molecules on polymer thin films in cleanroom facilities.

- Operated and maintained high-value **laser systems, AFM, and precision optical benches**, ensuring nanometer-scale alignment.

- Analyzed biomolecule deposition patterns using **Atomic Force Microscopy (AFM)** with calibration and probe handling expertise.

- Served as **Teaching Assistant for Physics 101**, supporting laboratory sessions and student coursework.

University of Alabama in Huntsville, USA

2010 – 2013

- Extended 2D electrostatic **Particle-in-Cell (PIC) plasma code** into a fully functional 3D electromagnetic simulation framework.

- Developed **Helmholtz coil field generation modules** from scratch for plasma thruster digital twins under NSF funding.

- Captured key plasma dynamics (**wave–particle interactions, plasma instabilities**) in high-fidelity numerical models.

- Implemented parallelization with **MPI/OpenMP** for scaling on university HPC clusters.

- Contributed to peer-reviewed publications in *Physics of Plasmas* via low-level code development and Linux automation.

Teaching & Communication

- **Content Creator – Compute Stories (YouTube)**

2024 – Present

- Produce educational and scientific communication videos simplifying complex concepts in **data science, computational modeling, and technical writing**.

- Built a small channel **Compute Stories** channel, making advanced research topics accessible to students and professionals.

- Skilled in **video editing (Final Cut Pro, DaVinci Resolve)**, **2D animation (Pencil2D)**, and **visual storytelling** to create engaging technical content.
- Developed strong **presentation, communication, and outreach skills**, bridging the gap between academic research and industry applications.

- **Workshop Instructor – UCLouvain, Belgium** 2018
 - Designed and delivered a hands-on MATLAB workshop for **50 undergraduate students**, focusing on parameter optimization for soil hydraulic modeling.
 - Guided students in using non-linear least squares fitting techniques to estimate van Genuchten parameters from laboratory-measured datasets.
 - Managed two batches of students, providing one-on-one support, verifying results, and ensuring participants successfully completed computational hydrology exercises.
 - Strengthened **technical training, mentoring, and classroom management skills** through interactive problem-solving sessions.
- **Graduate Teaching Assistant – Alabama A&M University, USA** 2013 – 2014
 - Taught year-long **Physics 101 and 102**, covering mechanics, electrostatics, and other fundamentals of physics.
 - Conducted weekly laboratory sessions, training students in experimental methods and ensuring hands-on learning outcomes.
 - Designed course materials, graded assignments, and provided academic mentoring to students from **diverse cultural and academic backgrounds**.
 - Gained practical experience in **inclusive teaching, student engagement, and cross-cultural communication**.

Publications

Journal Articles

1. Rao, S., et al. (under review). When Does Random Forest Soil-Specific Calibration Improve SAR-Based Soil Moisture Estimates? *Remote Sensing Letters*, submitted.
2. Rao, S., et al. (under review). Integrated Modeling Approaches for Agricultural Digital Twins: The Role of PBM, ABM, ML, and Model Coupling. *In Silico Plants*, submitted.
3. Rao, S., et al. (in preparation). Soil–Moisture–Temperature Coupled Dataset. Intended submission: *Sci Data*.
4. Rao, S., et al. (2020). Imaging plant responses to water deficit using electrical resistivity tomography. *Plant and Soil*, 29 citations.
5. Rao, S., et al. (2020). Sensing the electrical properties of roots: A review. *Vadose Zone Journal*, 19(1), 71 citations.
6. Rao, S., et al. (2019). Impact of maize roots on soil–root electrical conductivity: A simulation study. *Vadose Zone Journal*, 18(1), 35 citations.
7. Singh, N., Rao, S., et al. (2013). Waves generated in the plasma plume of helicon magnetic nozzle. *Physics of Plasmas*, 20(3), 27 citations.
8. Rao, S., Singh, N. (2012). Numerical simulation of current-free double layers created in a helicon plasma device. *Physics of Plasmas*, 19(9), 39 citations.

9. Singh, N., Rao, S. (2012). Plasma turbulence driven by transversely large-scale standing shear Alfvén waves. *Physics of Plasmas*, 19(12), 3 citations.

Books / Monographs

1. Rao, S. (2025). *Digital Twins: From Apollo Missions to Smart Farming*. Notion Press. ISBN: 979-8900231457. (Available on Amazon: <https://www.amazon.in/dp/B0FP5JS1KL>)

Book Chapters

1. Rao, S., Ranganath, P. (2025). Climate-Resilient Agriculture: Leveraging Language Models for Mitigation and Adaptation. In *Mitigation and Adaptation Strategies Against Climate Change in Natural Environments*.
2. Rao, S., Ranganath, P. (2025). Unmanned Aerial Vehicles (UAVs) as Sensor-Driven Data Feeders for Agricultural Digital Twins. Book chapter (submitted to Taylor & Francis).

Conference Presentations

1. Rao, S., et al. (2023). Random Forest for Soil Moisture Retrieval using Satellite Backscatter. Poster presented at *Soil Moisture Workshop*, IIT Bombay.
2. Rao, S., et al. (2019). Investigation of electrical anisotropy as a root phenotyping parameter: Numerical study with root water uptake. *Geophysical Research Abstracts*, 21.
3. Rao, S., et al. (2019). Relationship between electrical anisotropy of soil-root continuum and geometrical architecture of root system. *National Symposium for Applied Biological Sciences*.
4. Rao, S., et al. (2017). A forward model for electrical conduction in soil-root continuum: a virtual rhizotron study. *4th International Workshop on Geoelectrical Monitoring*.
5. Rao, S., et al. (2017). Characterizing root system characteristics with Electrical resistivity Tomography: a virtual rhizotron simulation. *EGU General Assembly Conference Abstracts*.

Peer Review & Professional Service

- Reviewer for *Nordic Machine Intelligence*
- Reviewer for *Plants in Silico*
- Reviewer for *PeerJ Computer Science*
- Reviewer for *Plant and Soil*
- Reviewer for *Vadose Zone Journal*
- Reviewer for *Agricultural Research*

Technical Skills

Programming and Scripting: Python (NumPy, Pandas, Plotly, Matplotlib), C++, FORTRAN, MATLAB, JavaScript (Vue.js, Chart.js), HTML/CSS, PyQt (GUI development)

Machine Learning and Data Science: Scikit-learn, TensorFlow, PyTorch, Keras, Random Forests, LSTM neural networks, Support Vector Machines, Computer Vision (OpenCV), Cross-correlation, Anomaly Detection, Seasonal Decomposition, Time-series Forecasting

Software Engineering: Docker, Git (version control), CI/CD workflows, WebSockets, API integration (financial data, remote sensing data), Hugo (static site development), Data Pipelines

High-Performance Computing: MPI, OpenMP, HPC clusters, Linux systems, Parallel Computing, Simulation Scaling

Modeling and Simulation: Digital Twin Development, Model Coupling (crop and root models, loose coupling methods), Numerical Methods, Finite Element Modeling (FEM), PIC Plasma Simulations, Hydrological and Biophysical Simulation Pipelines

Data Visualization: Interactive Dashboards (Plotly, Vue.js, Leaflet, Chart.js), Scientific Animations, Visualization for Remote Sensing Data, Custom Visualization for Soil–Moisture–Temperature Dynamics

Instrumentation and Experimental: Satellite Remote Sensing (SAR, LAI, backscatter analysis), Geoelectric Methods, Atomic Force Microscopy (AFM), Optical Test Benches, Lock-in Amplifiers, Field Data Collection Protocols

Science Communication and Media: Technical Writing, Video Editing (Final Cut Pro, DaVinci Resolve), 2D Animation (Pencil2D), Educational Content Creation (YouTube – Compute Stories)

Professional Development

- Land in Focus - Basics of Remote Sensing, EO College November 2022
- Advanced HPC training workshops and computational modeling courses
- Intro to Reinforcement Learning, University of Alberta, CoursEra, Aug 2025

Volunteer Experience

Blog Committee Member — Young Hydrologic Society (YHS) April 2025 – Present

- Selected to contribute to the YHS Blog Committee, creating educational content for early career hydrologists.
- Develop blog posts on topics related to computational hydrology, digital twins, and environmental modeling.
- Support the YHS mission of promoting participation of early career researchers in the hydrologic science community.