

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**.

Invited Talks & Guest Lectures

- **A Classical Computational Person Looks at Quantum Computing: A Computational Scientist's View of Quantum Computing.** Invited guest lecture, Department of Electronics and Communication Engineering, **Kumaraguru College of Technology (KCT)**, Coimbatore, India, *October 2025*. Talk connected the mathematical and computational foundations of classical modeling, especially matrix-based systems with emerging quantum algorithms, emphasizing continuity between numerical simulation, linear algebra, and quantum computation.

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). High-Frequency Soil Hydrothermal Dynamics in a Semi-Arid Agricultural Catchment: A Decade of 15-Minute Resolution Observations (2016-2025). 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.