National Aeronautics and Space Administration

NASA CMS CARBON MONITORING SYSTEM

Savanna-Bio: Biomass estimation with new spaceborne missions for MRV in Dry Forests and Savannas

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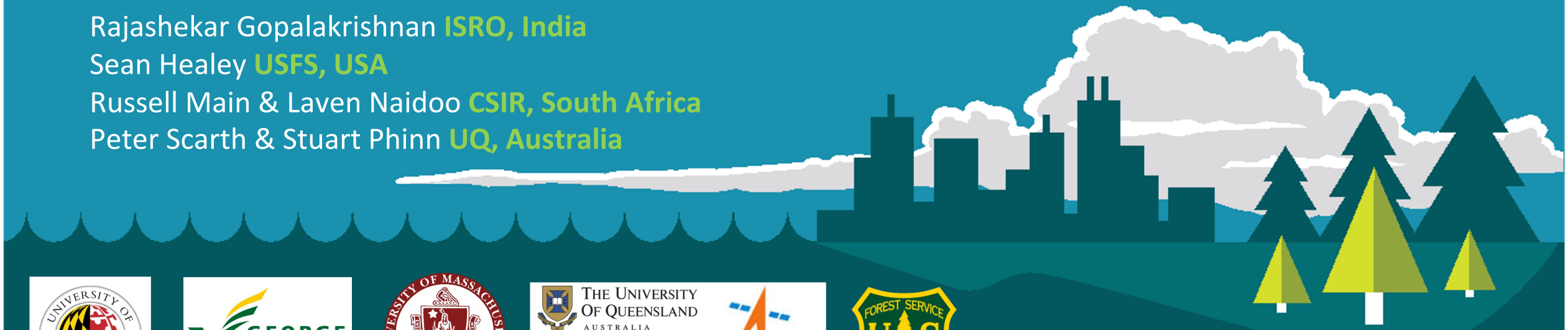


PRESENTATION OUTLINE

1. **Background and research objectives**

2. **Relevance and connections to ongoing synthesis efforts**

3. **Top-level science results**
   a. Performance of GEDI and ICESat-2
   b. InSAR-based estimation of canopy height
   c. High-resolution biomass estimation

4. **Stakeholder engagement (South Africa & Australia)**

5. **Future directions**

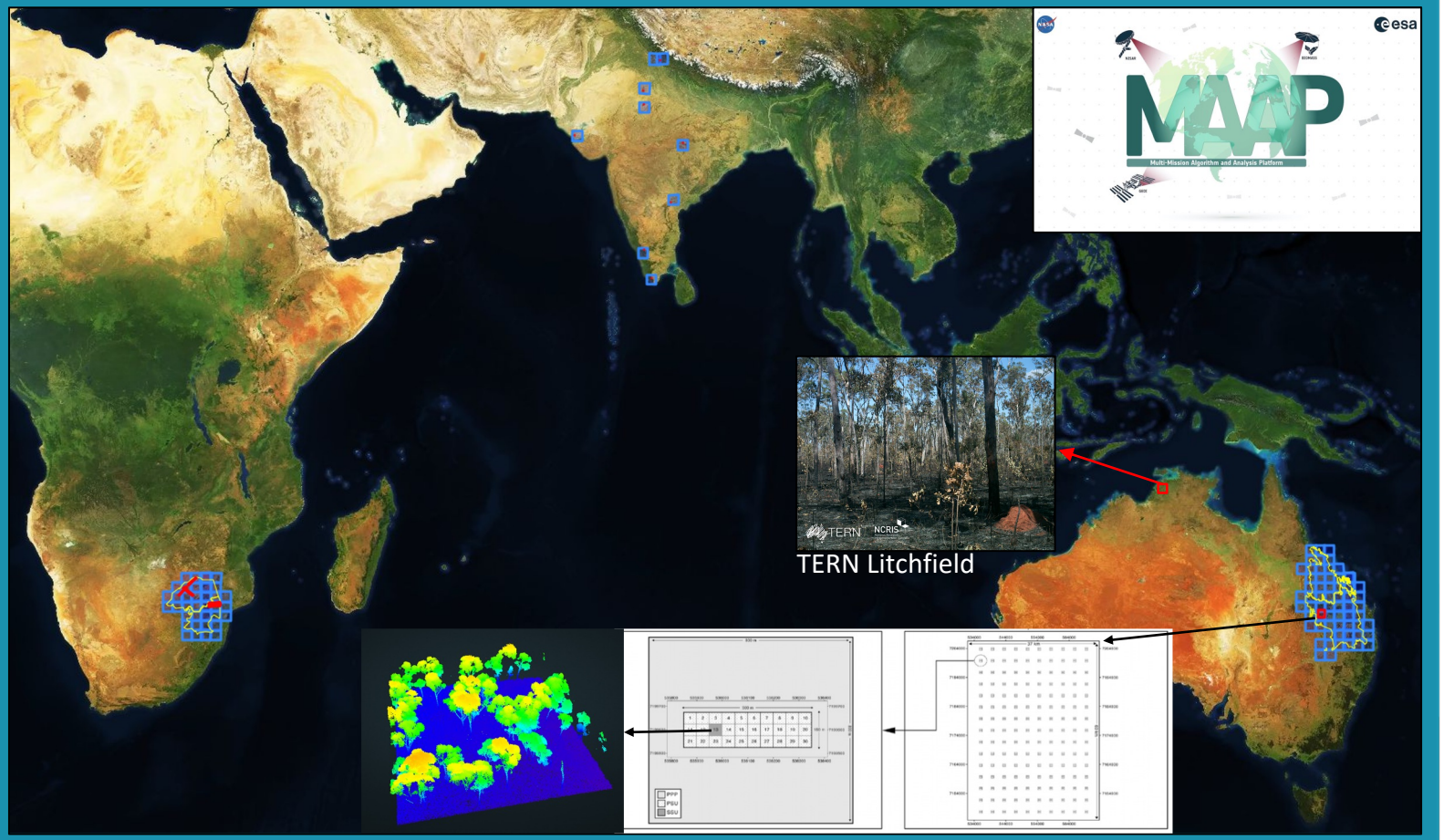
OBJECTIVES AND RESEARCH PLAN (2021 – 2024)

1. **Reducing uncertainty in training samples**
   Validating and refining satellite lidar (GEDI and ICESat-2) estimates of structure and biomass for dry forests and savannas

2. **Canopy structure and biomass mapping in savannas**
   Develop prototype structure and biomass maps for international pilot sites using satellite lidar and SAR (Sentinel-1A/1B and ALOS PALSAR-2) datasets

3. **Evaluation of uncertainty**
   Use independent field and airborne data to validate the products and evaluate the uncertainty following the CEOS Land Product Validation protocol for biomass

4. **Assessment of woody change**
   Working with stakeholders to quantify the impacts of woody degradation and regrowth on aboveground biomass and carbon stock change with reference to existing MRV activity data



Collaboration, product development and dissemination implemented on the NASA Multi-Mission Algorithm and Analysis Platform (MAAP)

RELEVANCE AND CONNECTIONS TO ONGOING SYNTHESIS EFFORTS

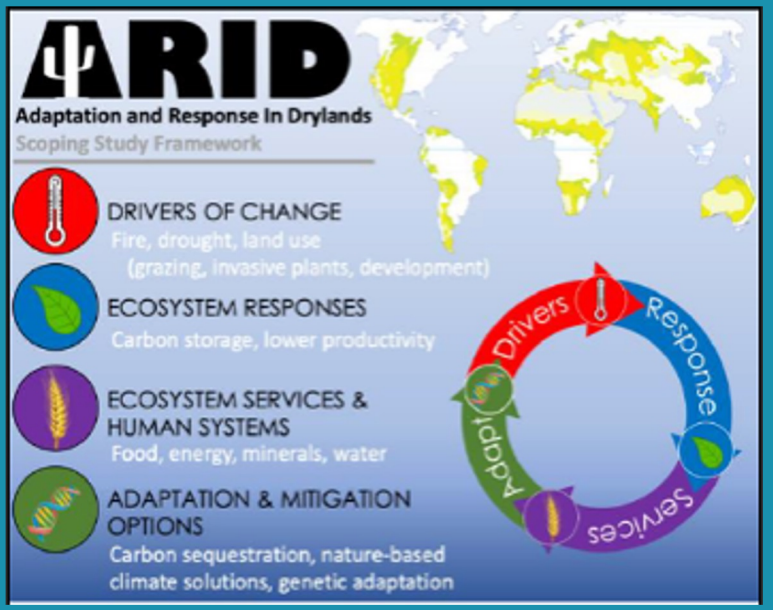
- **Savannas cover more than 20% of the earth and account for the third largest stock of global aboveground biomass**
  - Tucker et al. (2023) showed that AGBD predictions can differ by up to 250% in sub-Saharan drylands

- **Our NASA CMS project is uniquely focused on savanna ecosystems**
  - Silva (2022) project has related objectives in Brazilian Cerrado
  - Coordinated comparison of products to demonstrate reductions in uncertainty (e.g., Biomass working group)

- **Preparing for the launch of NISAR, the L- and S-band SAR**
  - Collaboration with ISRO National Remote Sensing Centre (NRSC) on cal/val of methods for our proposed data products
  - Collaboration with stakeholders in Australian and South African Government Agencies looking to NISAR for landscape monitoring
  - Current best estimate of launch: April 2024

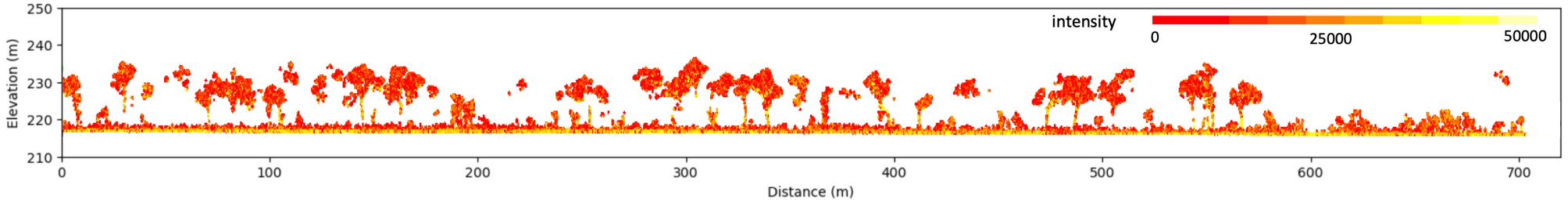
- **Relevant to NASA field campaign scoping study (ARID)**

- **Informs the CEOS Aboveground Biomass Validation protocol (Phase 2)**

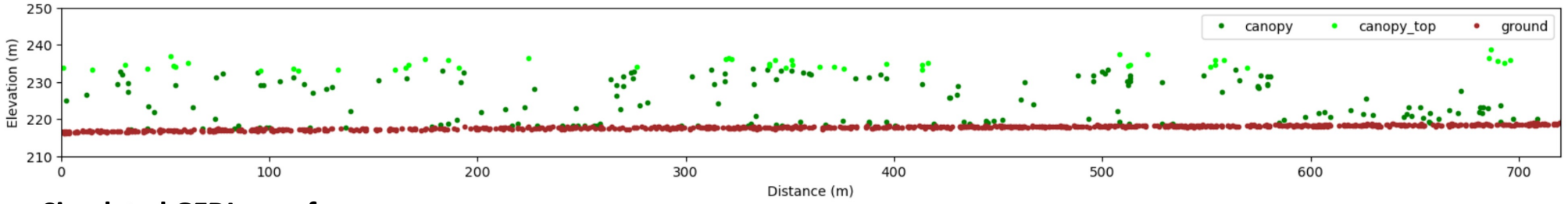


PERFORMANCE OF GEDI & ICESat-2 — MEASUREMENT DIFFERENCES

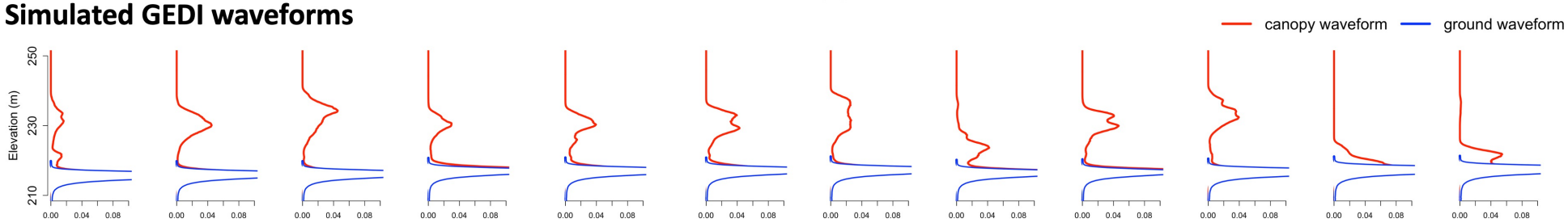
UAV lidar cross section



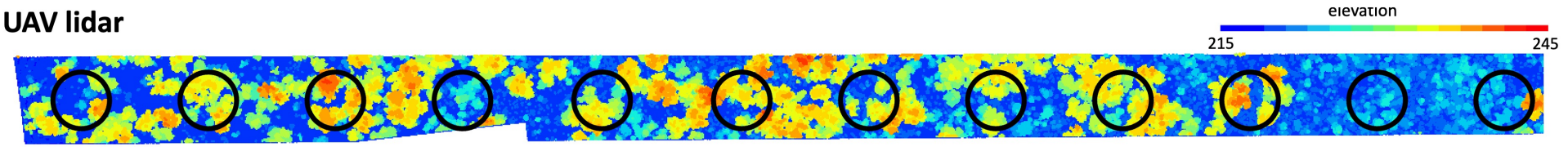
ICESat-2 ATL08 photon classification



Simulated GEDI waveforms

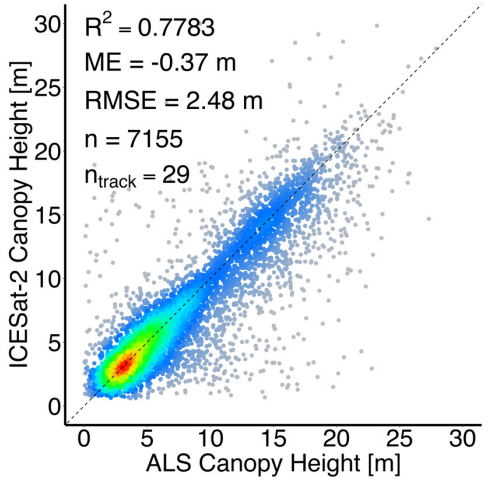


UAV lidar

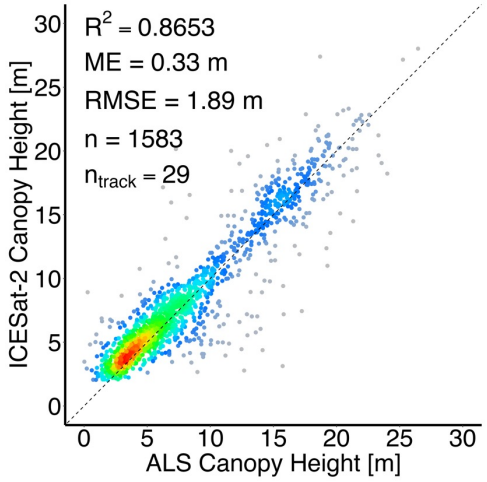


PERFORMANCE OF GEDI & ICESat-2 — INDEPENDENT VALIDATION

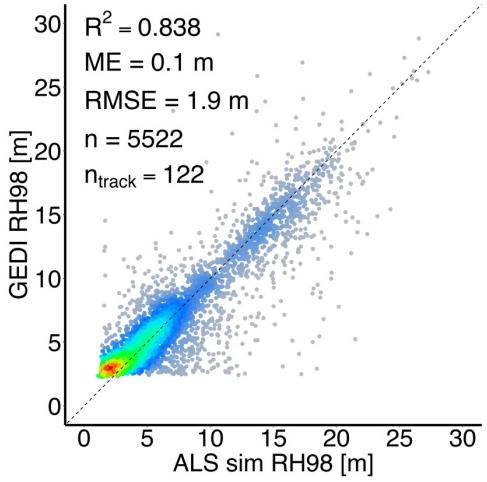
ICESat-2 (20 m)



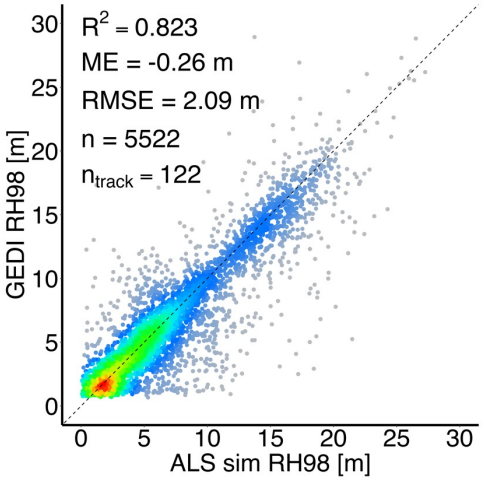
ICESat-2 (100 m)



GEDI Level-2A (25 m)



GEDI Deconvolved



Refined GEDI and ICESat-2 canopy height estimates reduce systematic deviation from reference data but increase variance

- Deconvolution (Gold's method) reduced deviation between GEDI RH98 and reference canopy height
- ICESat-2 20 m segments reduced deviation between ATL08 P98 and reference canopy height

ELSEVIER

Remote Sensing of Environment

Volume 285, 1 February 2023, 113402

First validation of GEDI canopy heights in African savannas

Xiaoxuan Li [a], Konrad Wessels [a], John Armston [b], Steven Hancock [c], Renaud Mathieu [d], Russell Main [e], Laven Naidoo [f], Barend Erasmus [g], Robert Scholes [h]

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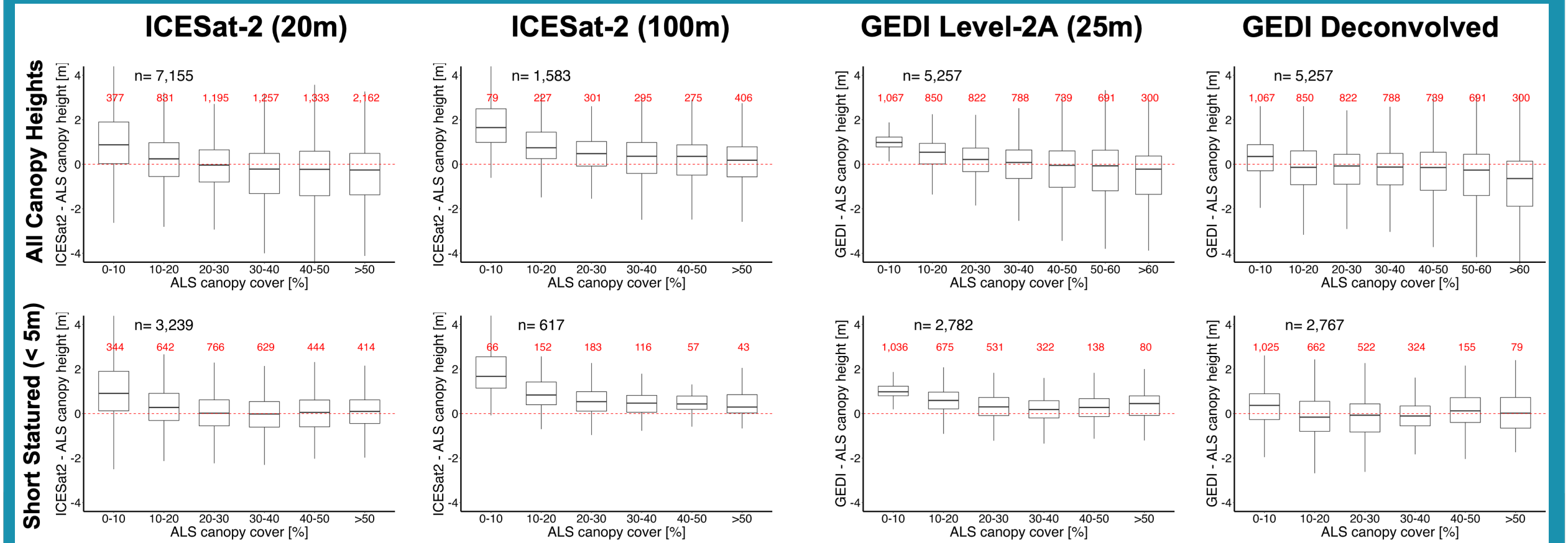
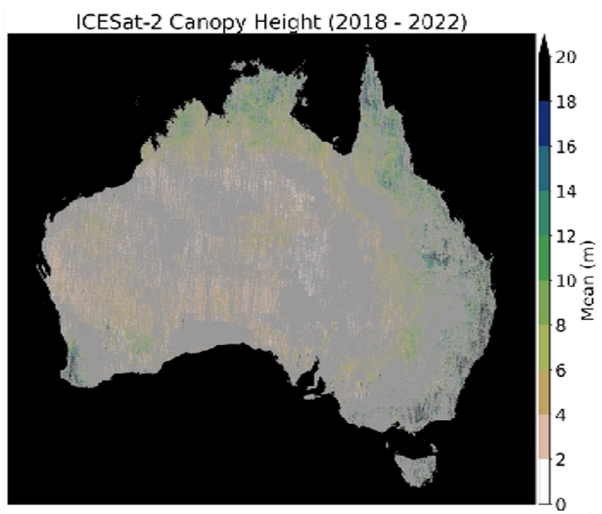
PERFORMANCE OF GEDI & ICESat-2 — INDEPENDENT VALIDATION

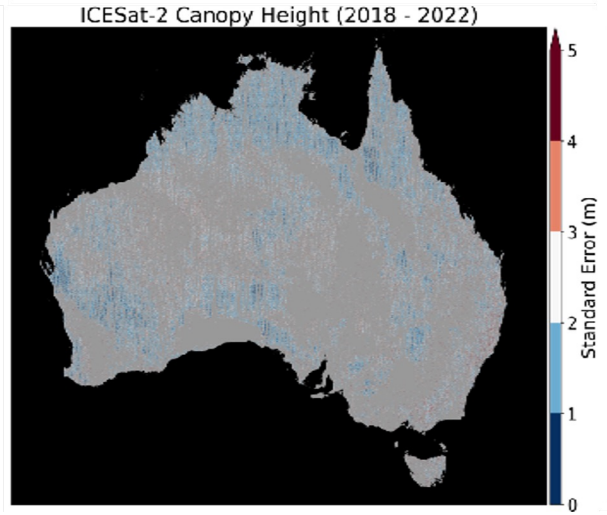


New GEDI and ICESat-2 canopy height estimates improve performance in low canopy cover and short-statured woody vegetation

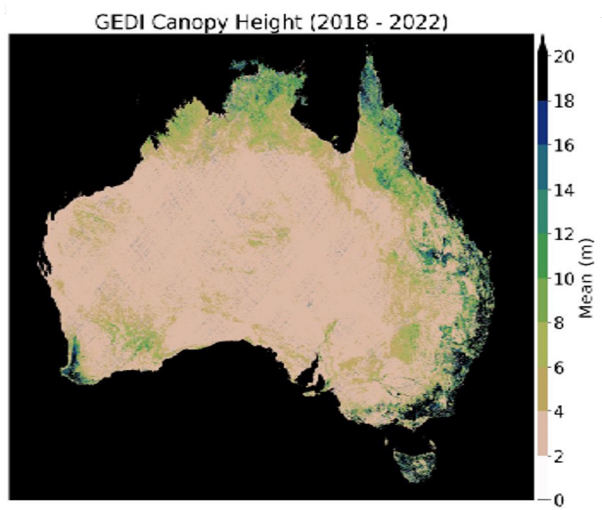
PERFORMANCE OF GEDI & ICESat-2 — EFFICACY FOR LARGE AREA MAPPING

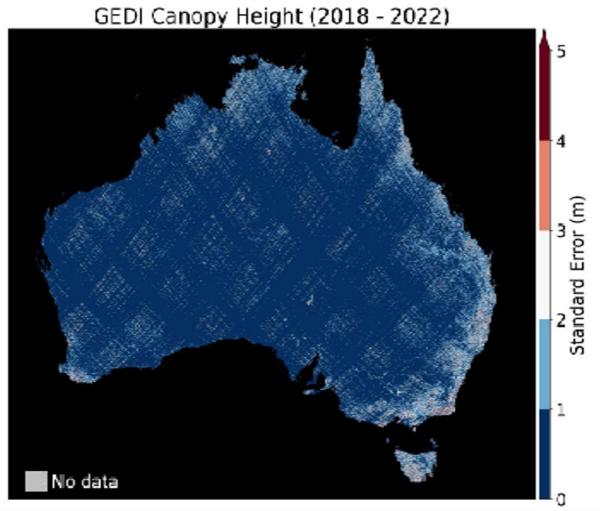
ICESat-2 20m segments



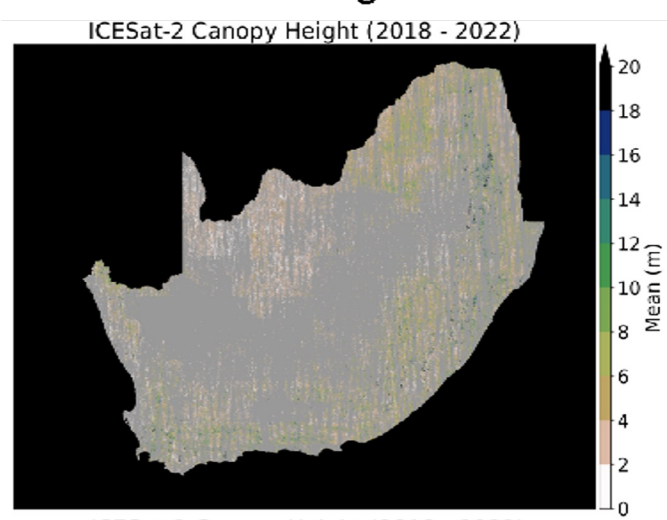


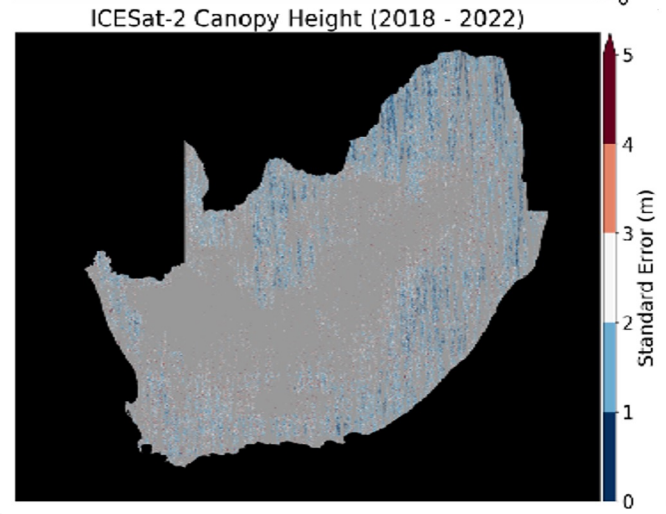
GEDI 25m



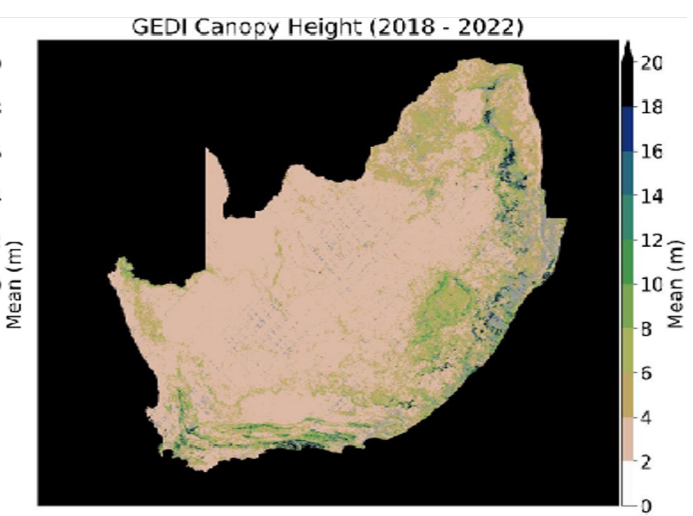


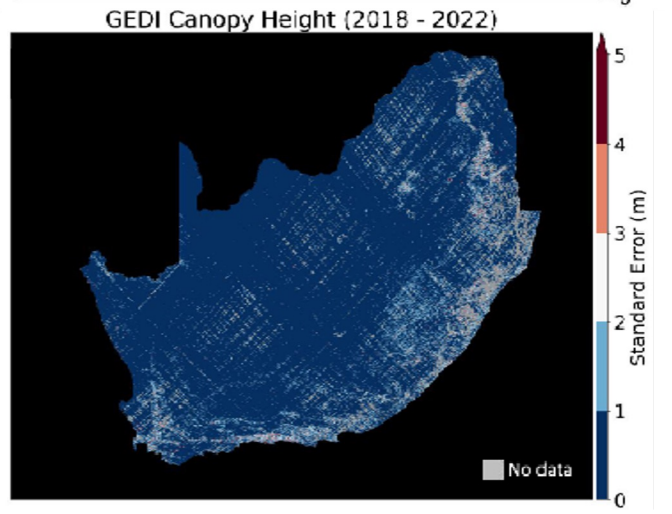
ICESat-2 20m segments



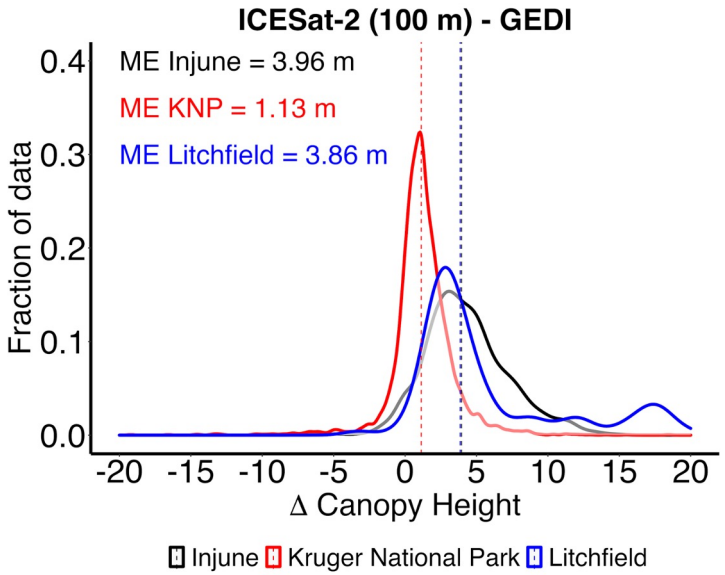


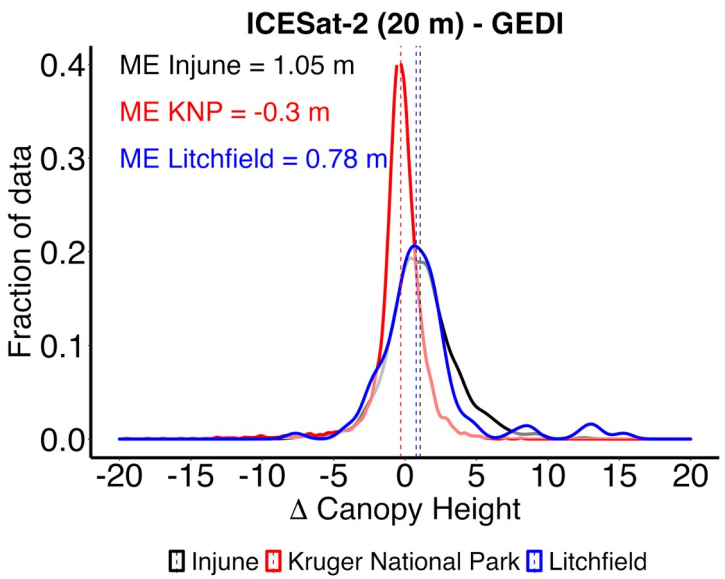
GEDI 25m

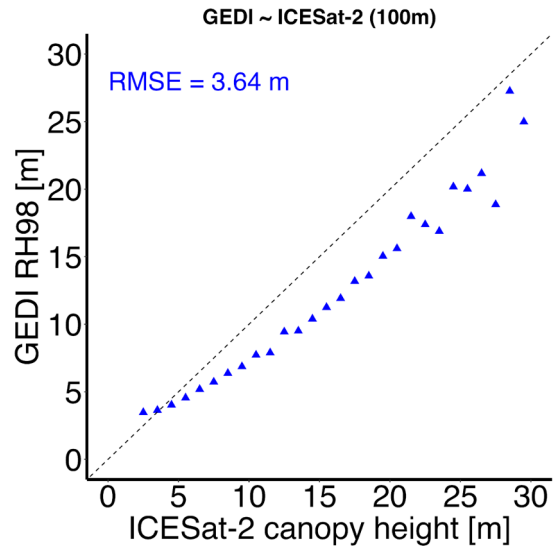


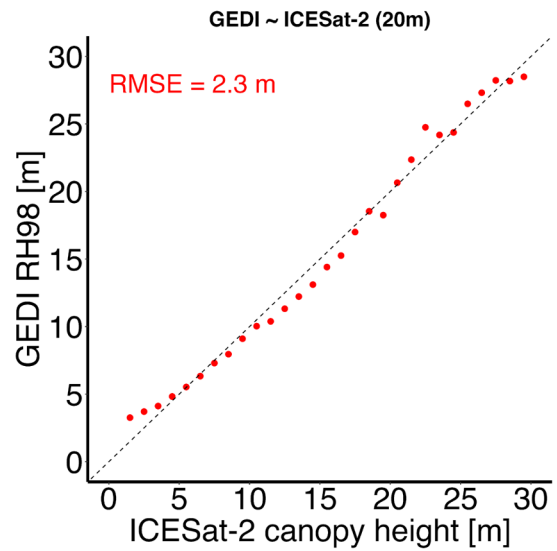


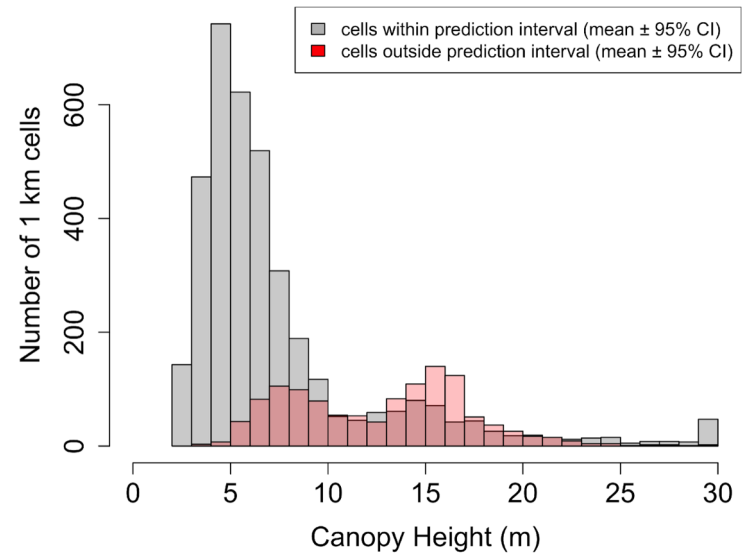
PERFORMANCE OF GEDI & ICESat-2 — EFFICACY FOR LARGE AREA MAPPING

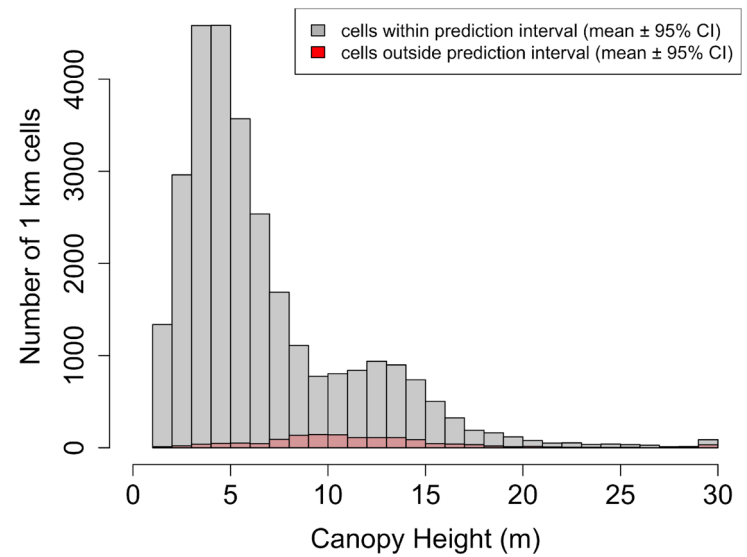










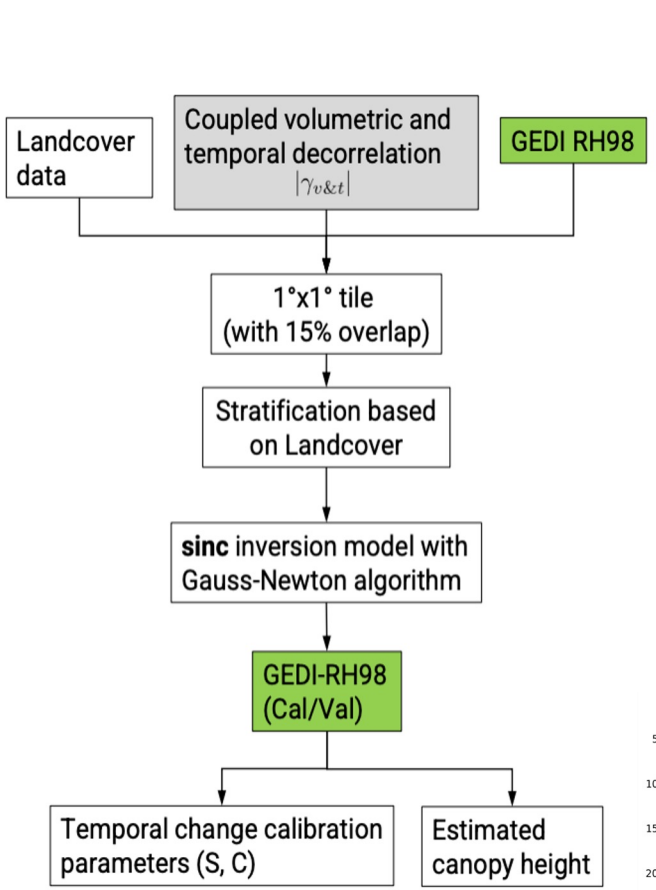


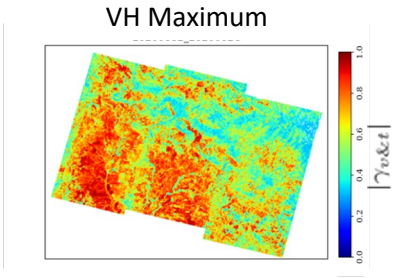
InSAR BASED ESTIMATION OF CANOPY HEIGHT

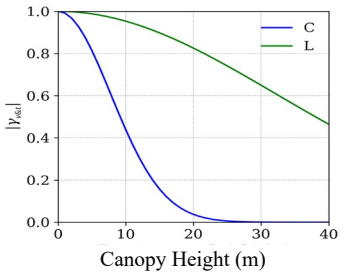
- **From a repeat-pass InSAR pair (t=12 days) the volume & temporal InSAR correlation ($\gamma_{v\&t}$) can be derived**
  - Inversion of canopy height requires local calibration of temporal change parameters from GEDI or ICESat-2

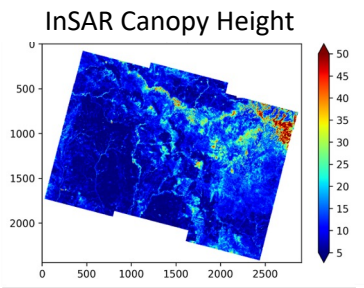
- **L- and C-band InSAR correlation**
  - Sensitivity to different canopy height ranges
  - Limited acquisitions from ALOS-2 (…NISAR)
  - Comparison with standard RCS approaches

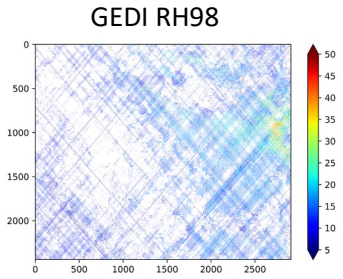
- **Current developments**
  - Implementation on the NASA MAAP
    Sentinel-1 (S1) coherence mosaics
  - Validation against ALS reference data
  - Application to S1 C-band and ALOS-2 L-band at high spatial resolution over the three pilot sites











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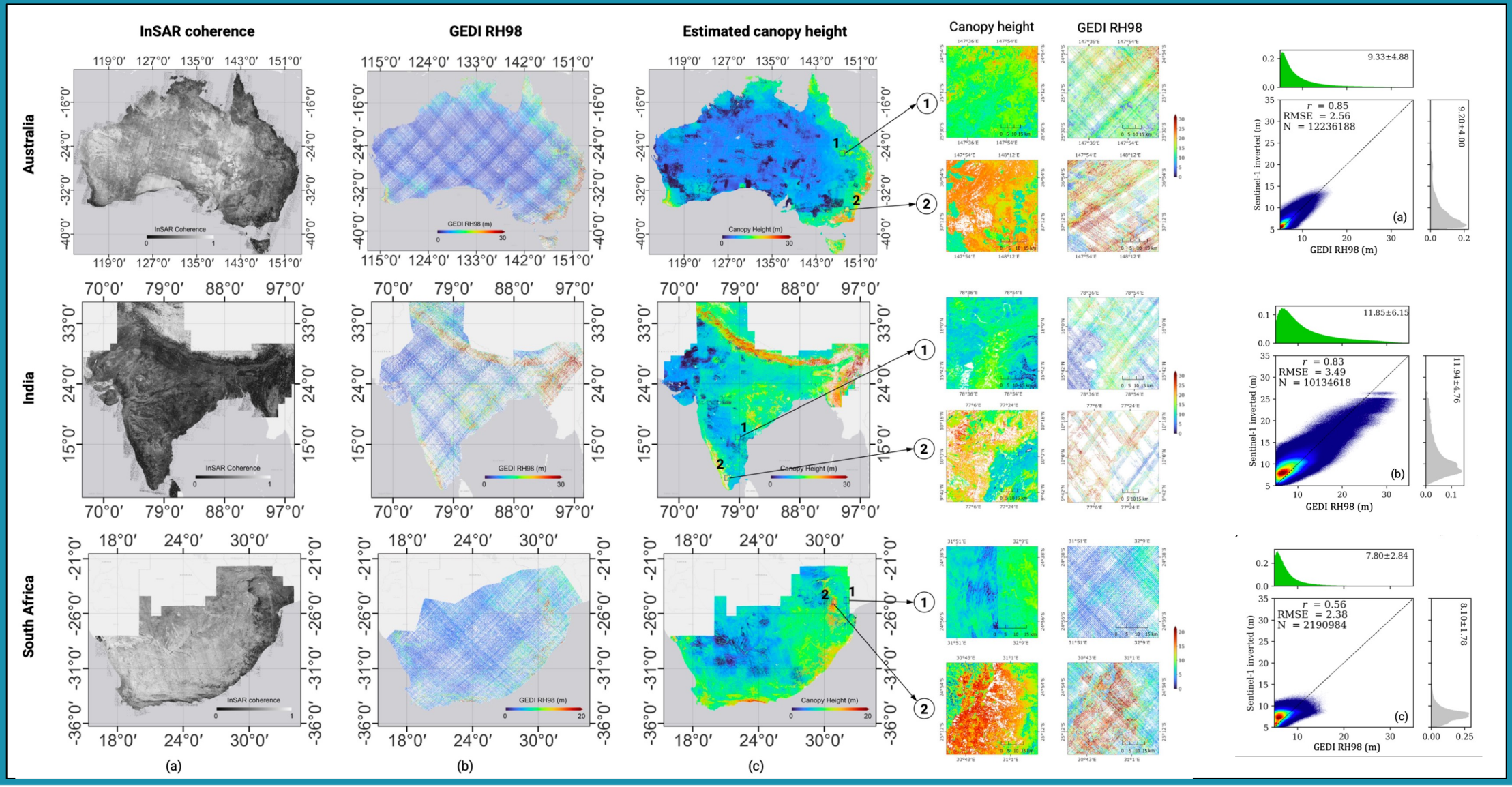
DEMONSTRATION OF InSAR BASED CANOPY HEIGHT ESTIMATION ON THE NASA MAAP



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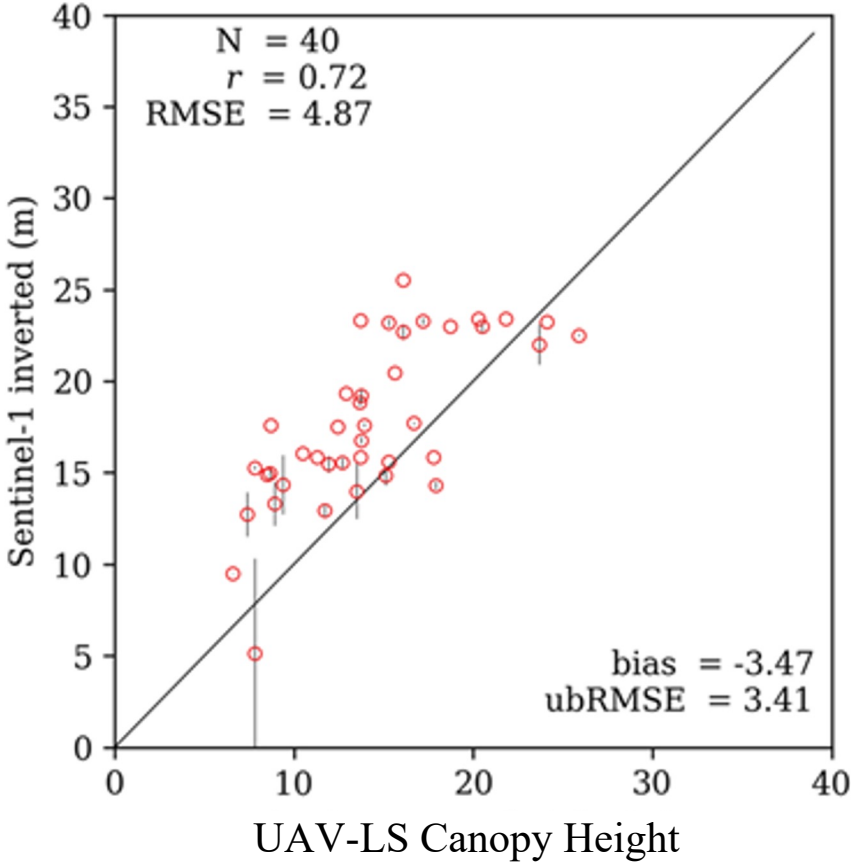
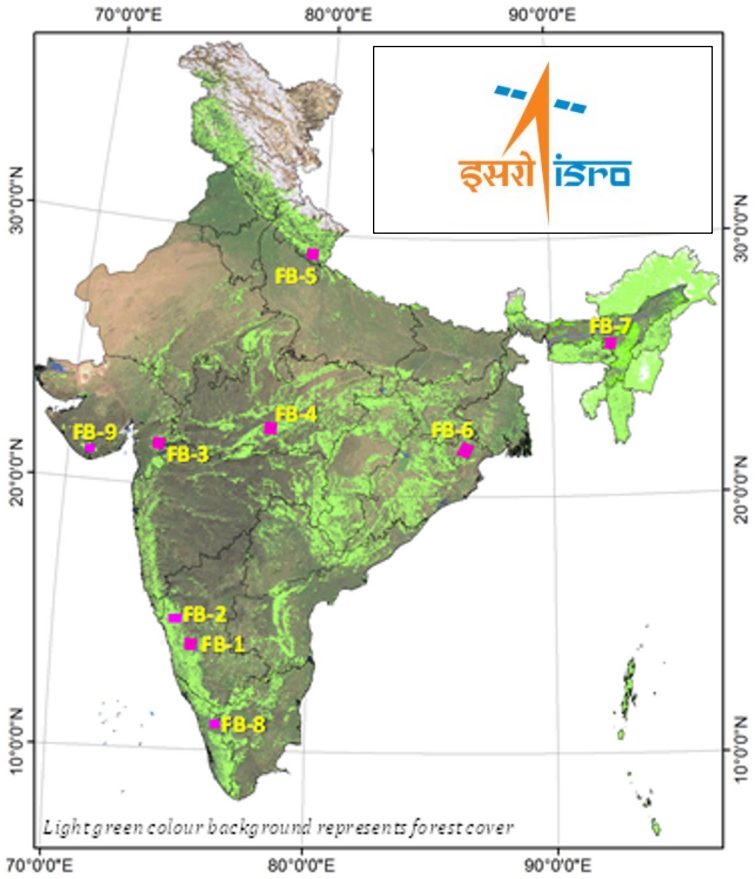


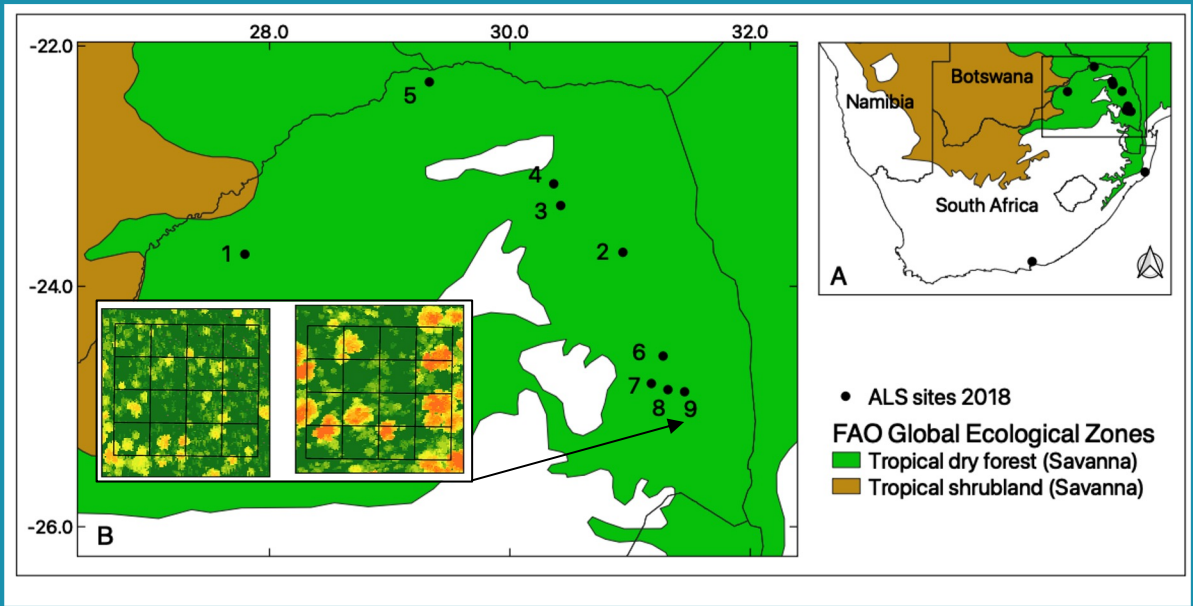


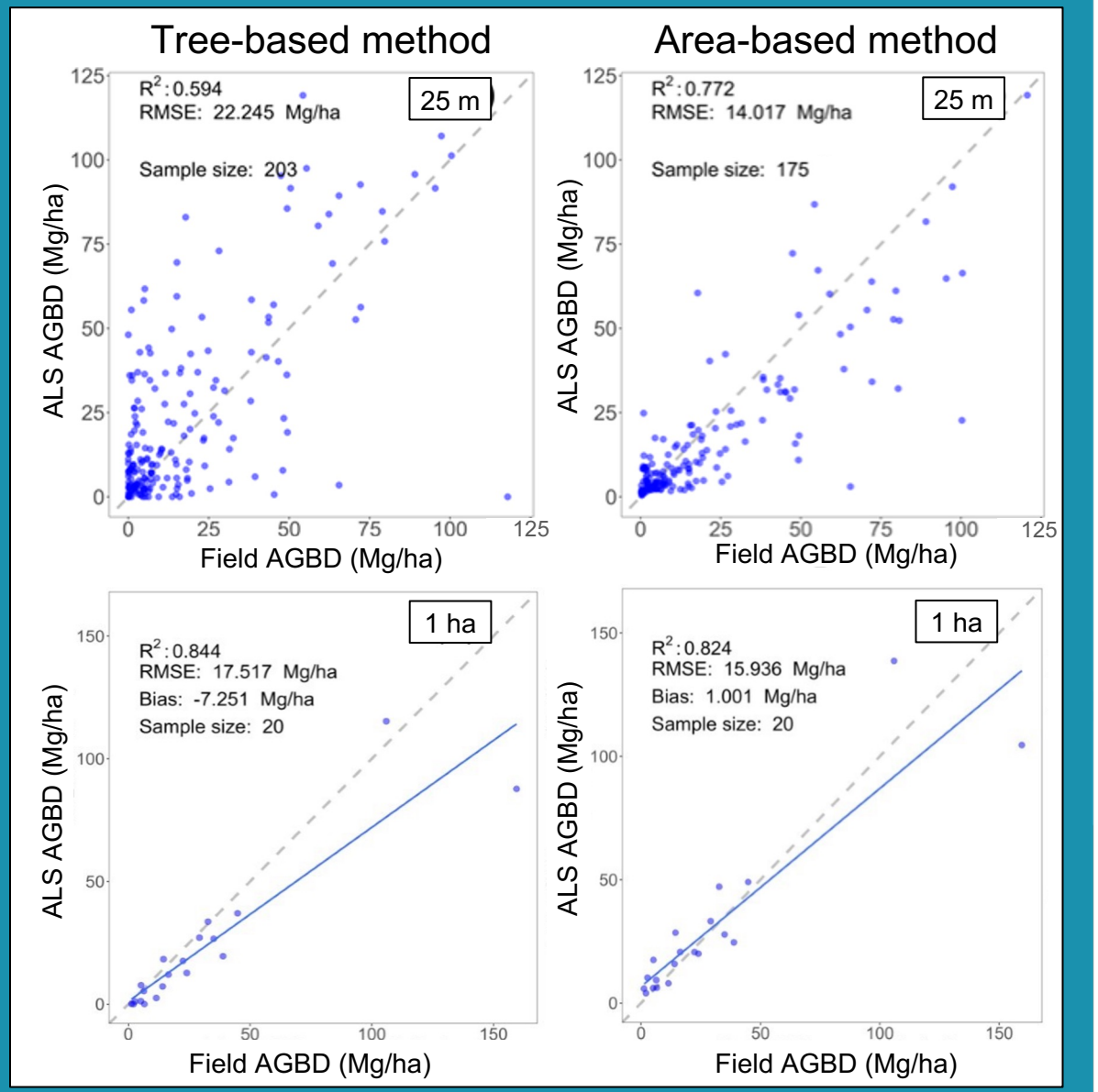
FB-1
FB-2
FB-4
FB-5
FB-8

Validation at Indian cal/val sites using reference estimates of canopy height derived from UAV Laser Scanning

HIGH-RESOLUTION BIOMASS ESTIMATION

- Reference ALS biomass maps required for validation of GEDI Level-4 products and the development of hierarchical models
- New field → ALS models are being developed for the pilot sites [***biomass ~ H x CC***]
- Field estimates of AGBD are based on local species-generalized allometry (Colgan *et al*., 2013)
- Area-based methods outperformed tree-based





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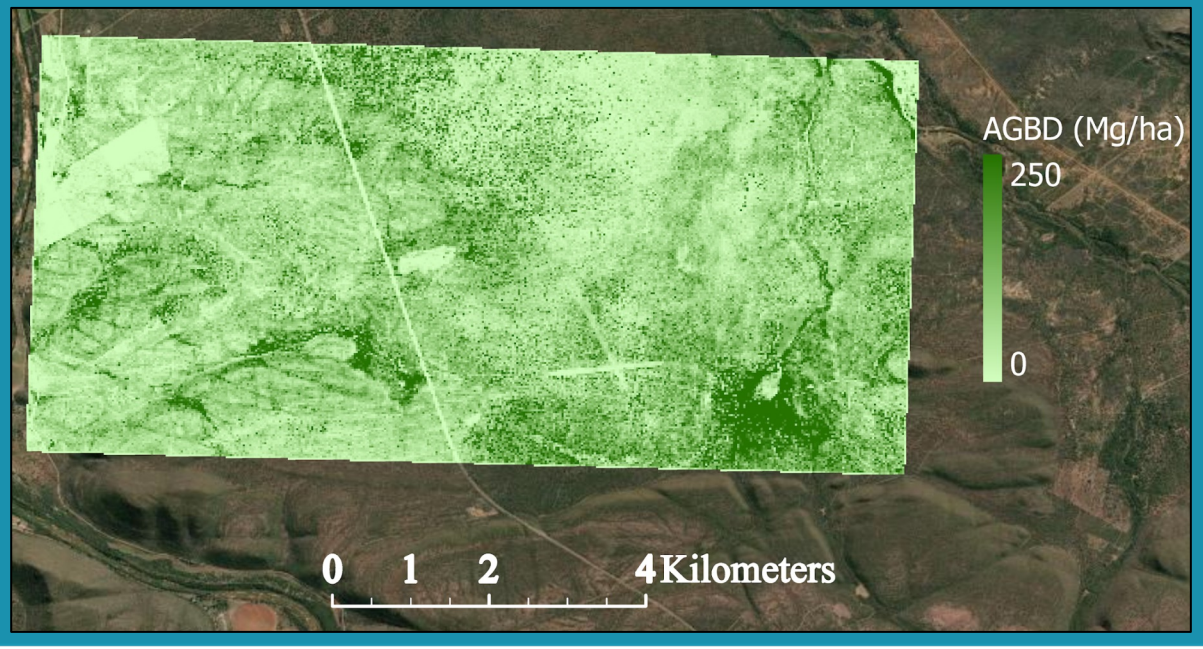
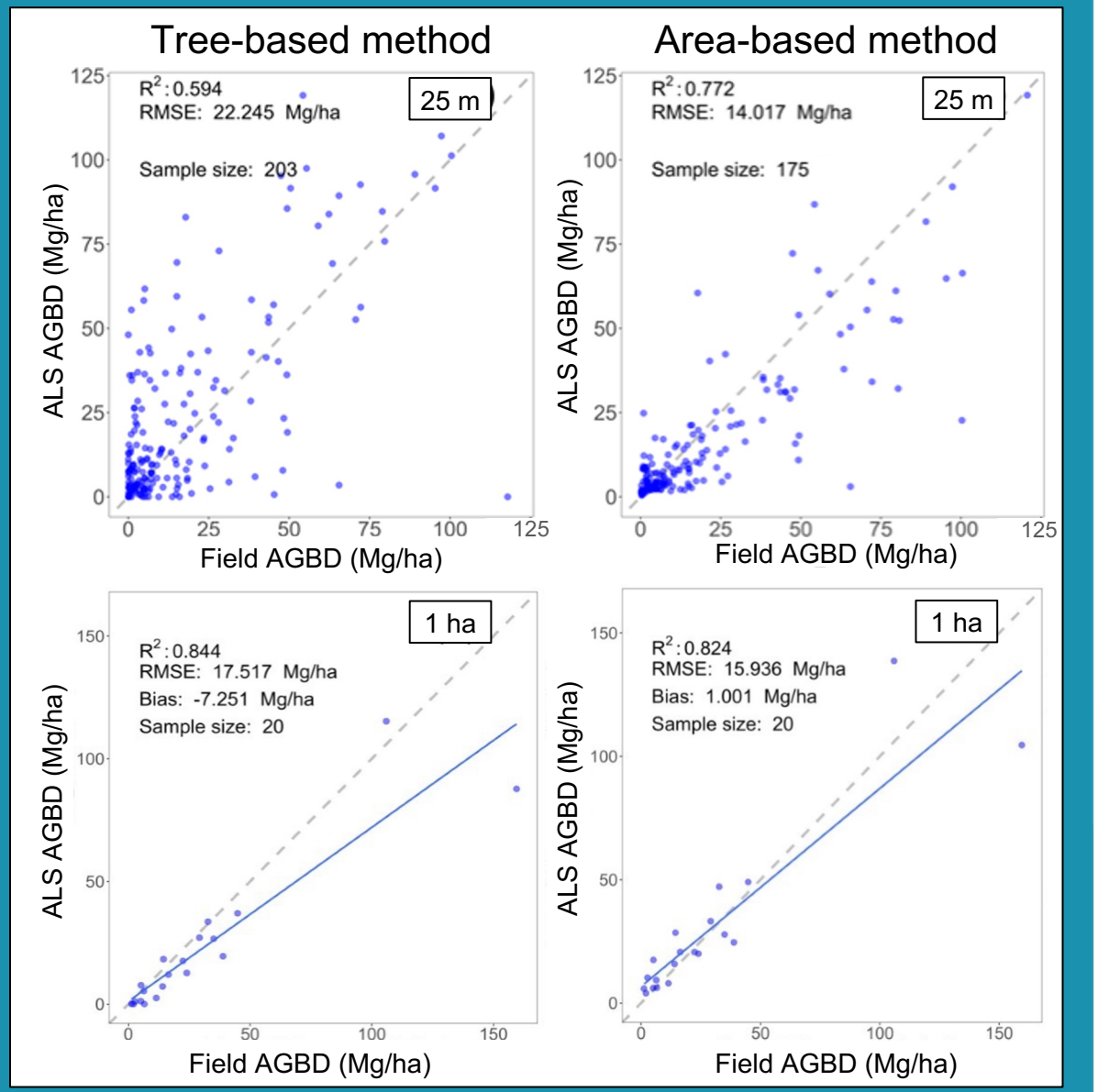




HIGH-RESOLUTION BIOMASS ESTIMATION

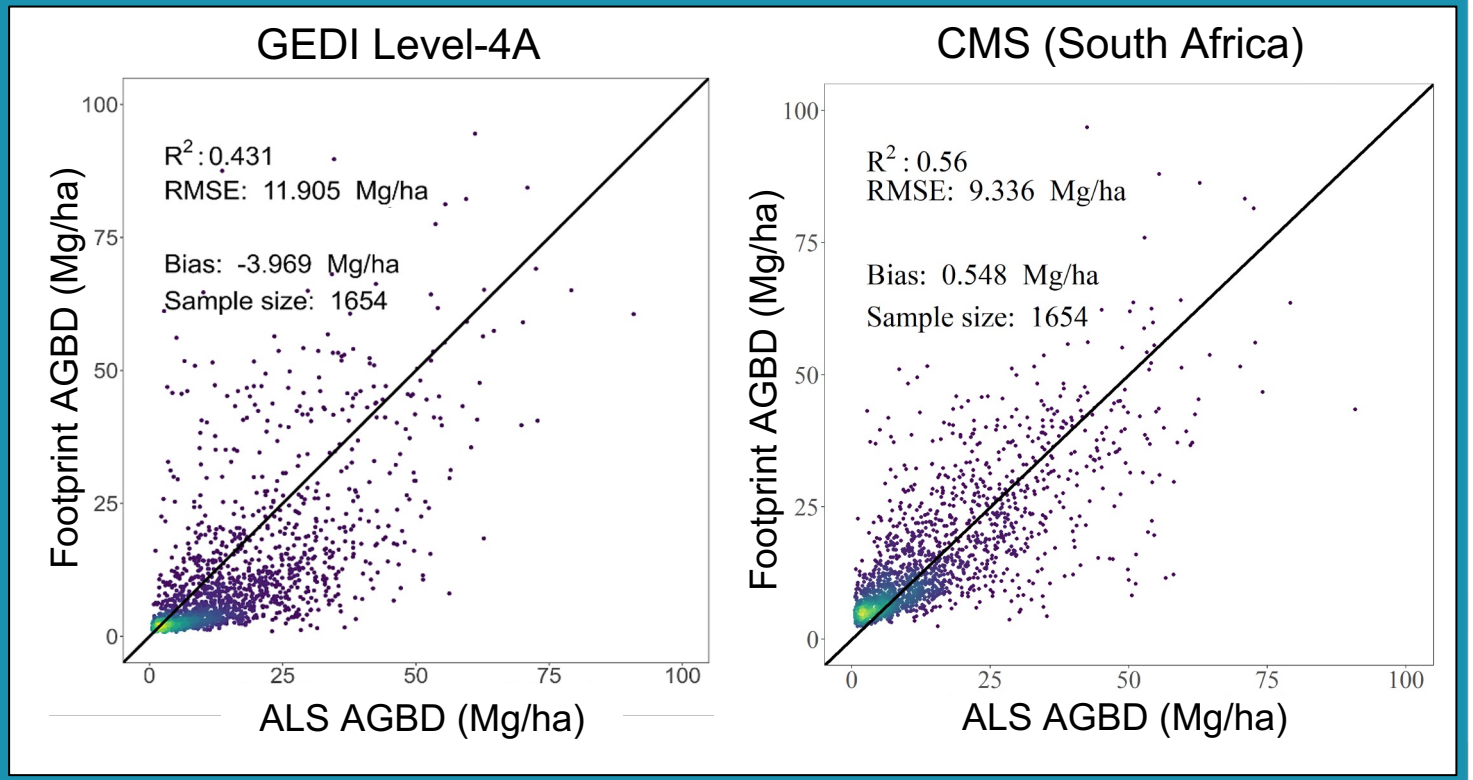
- **The GEDI footprint model applied to Southern Africa systematically underestimates aboveground biomass**

- **A Generalized Linear Model (GLM) provided a regionally applicable footprint model**
  biomass ~ RH98 + RH50 + FHD

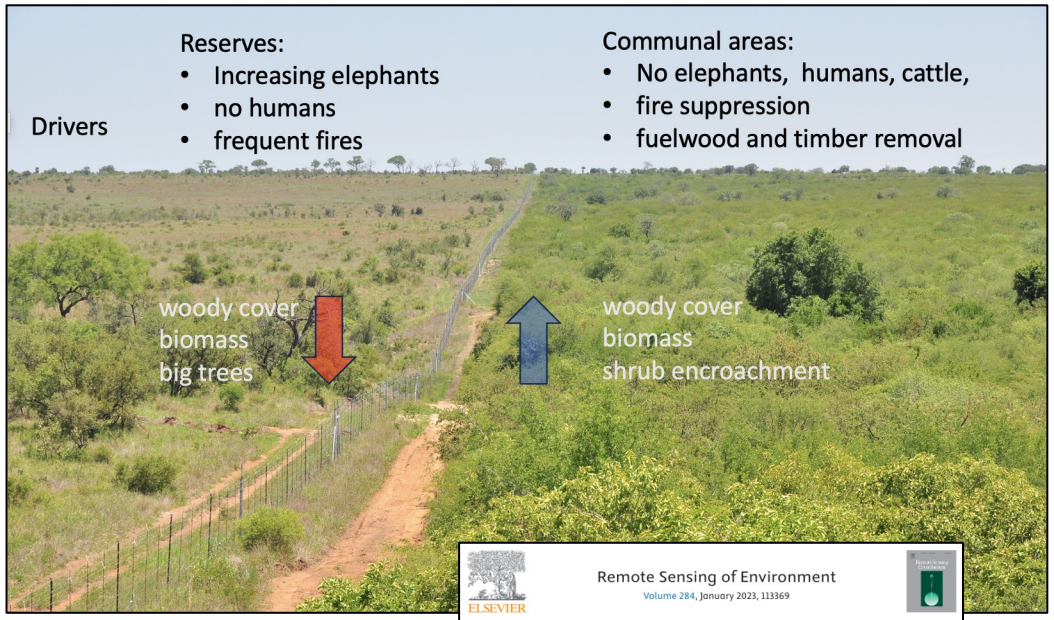
- **Colocation of GEDI and contemporaneous ALS data**
  - avoids simulation of GEDI waveform metrics
  - no need for a measurement error model

- **Hierarchical model development**
  - field to GEDI ✓
  - ALS to GEDI ✓
  - GEDI to RCS/InSAR metrics

- **Generalized Hierarchical Model Based Inference**
  - GHMB integrated in the GEDI mission for fusion
  - Saarela et al. (2018) provides basis for temporal correlation in the model parameters and estimates



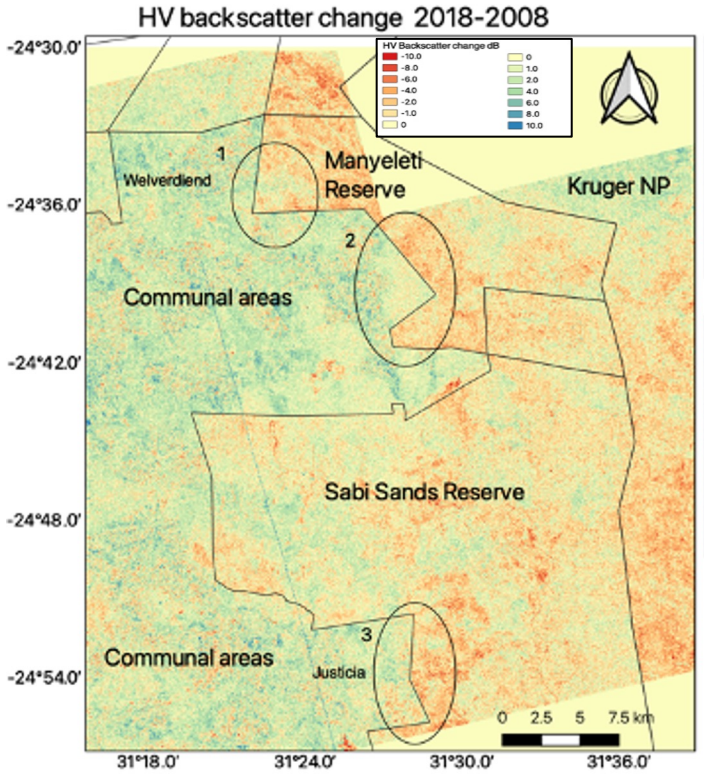
NEXT STEP: ESTIMATION OF WOODY STRUCTURE AND BIOMASS CHANGE



Remote Sensing of Environment
Volume 284, January 2023, 113369

Quantifying the sensitivity of L-Band SAR to a decade of vegetation structure changes in savannas

Konrad Wessels [a], Xiaoxuan Li [a], Alexandre Bouvet [b], Renaud Mathieu [c], Russell Main [d], Laven Naidoo [e], Barend Erasmus [f], Gregory P. Asner [g]

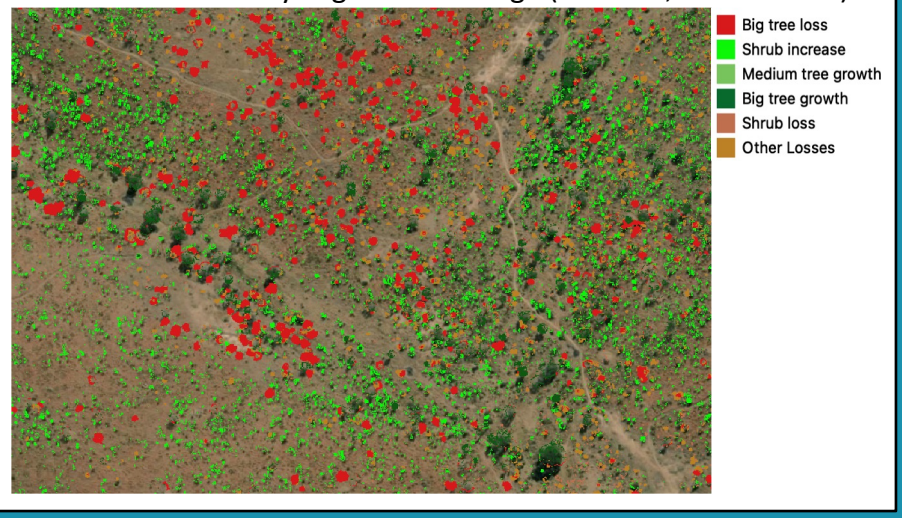


Prototype aboveground biomass products for Lowveld / Greater Kruger National Park (KNP) in South Africa are being generated using ALOS-2 ScanSAR and FBD time-series

STAKEHOLDER ENGAGEMENT (SOUTH AFRICA)

- **Department of Environment, Forestry and Fisheries (DEFF)**: MRV of Agriculture, Forestry and Other Land Use (AFOLU) sector to quantify and report on GHG emissions and impacts, and emission reduction responses
- **South African National Parks (SANParks)**: Carbon consequences of management decisions (fire and elephant density) → *Prototype products*
- **Insights**: High elephant densities lead to loss of AGBD / carbon in conservation areas → *Field and airborne campaign in Oct / Nov 2023*

2008-2018 woody vegetation change (Lowveld, South Africa)

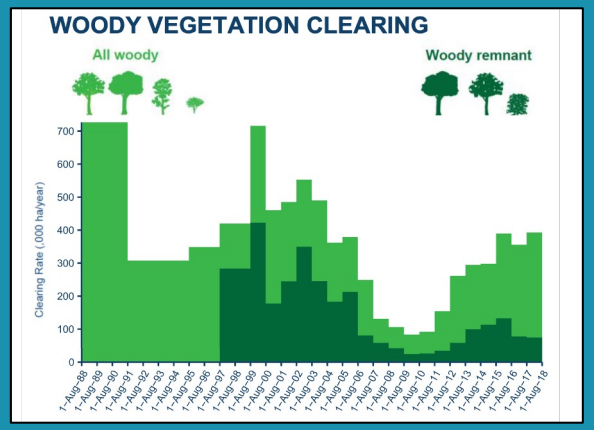


SANParks Scientific Services (Jan 2023)

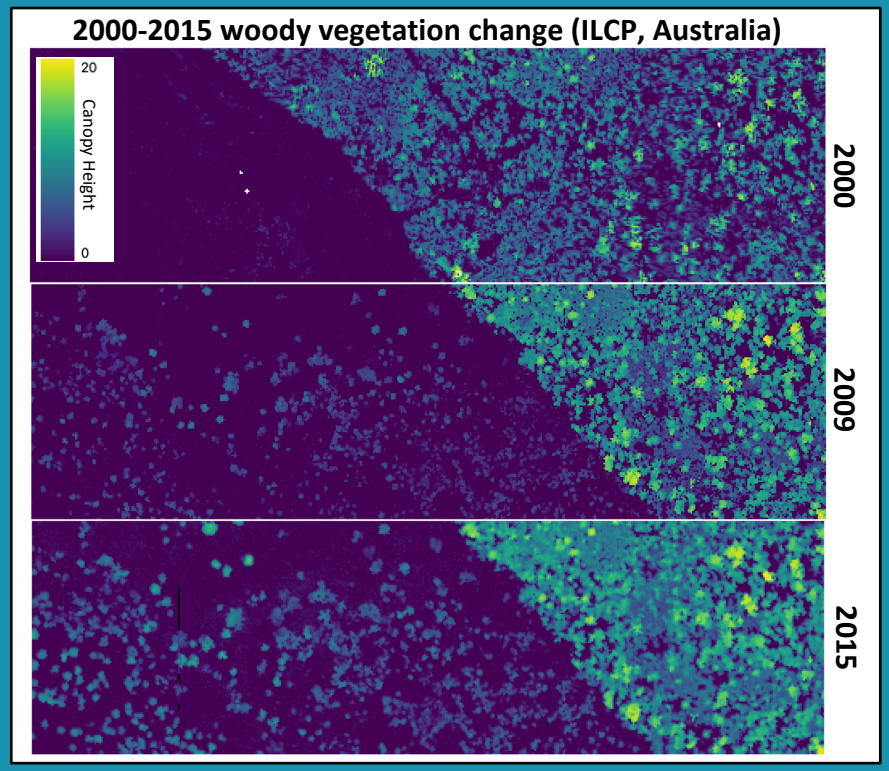
South Africa Environmental Observation Network (SAEON)

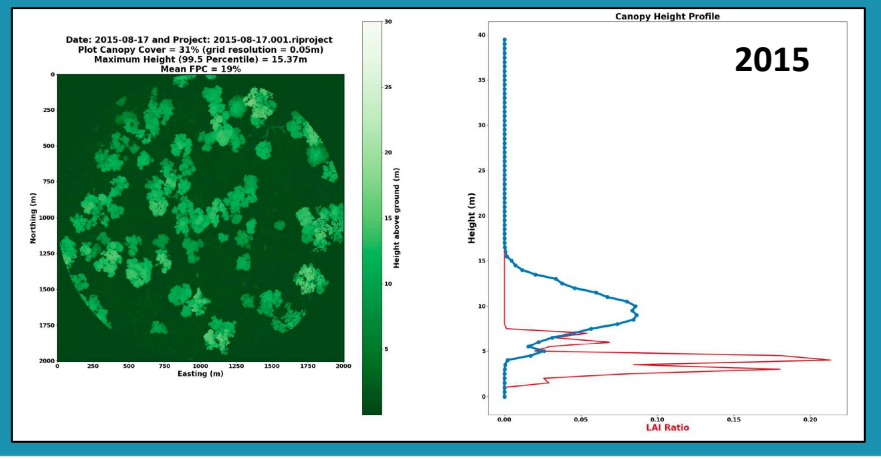
STAKEHOLDER ENGAGEMENT (AUSTRALIA)

- **Queensland Department of Environment and Science:** Increasing interest in verifiable frameworks under “Accounting for Nature” type frameworks, such as the Queensland Land Restoration Fund; and lowering measurement error for Australia’s Emission Reduction Fund
- **Joint Remote Sensing Research Program (University of Queensland, Brisbane)**: Responding to the increasing number of landholders, private organizations and NGO’s are interested in biomass change → *Prototype products and field & airborne campaign in May / June 2024*



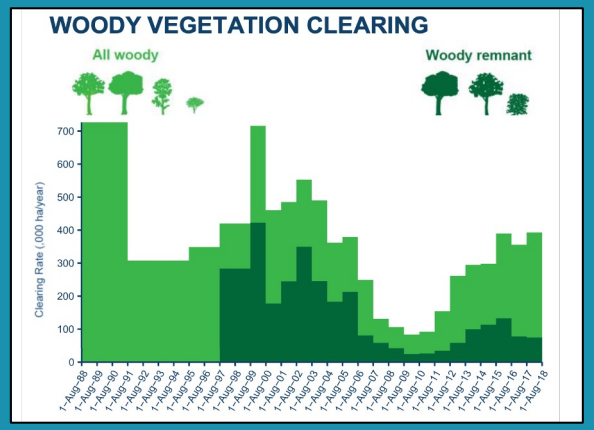
Queensland Department of Environment and Science (2023)



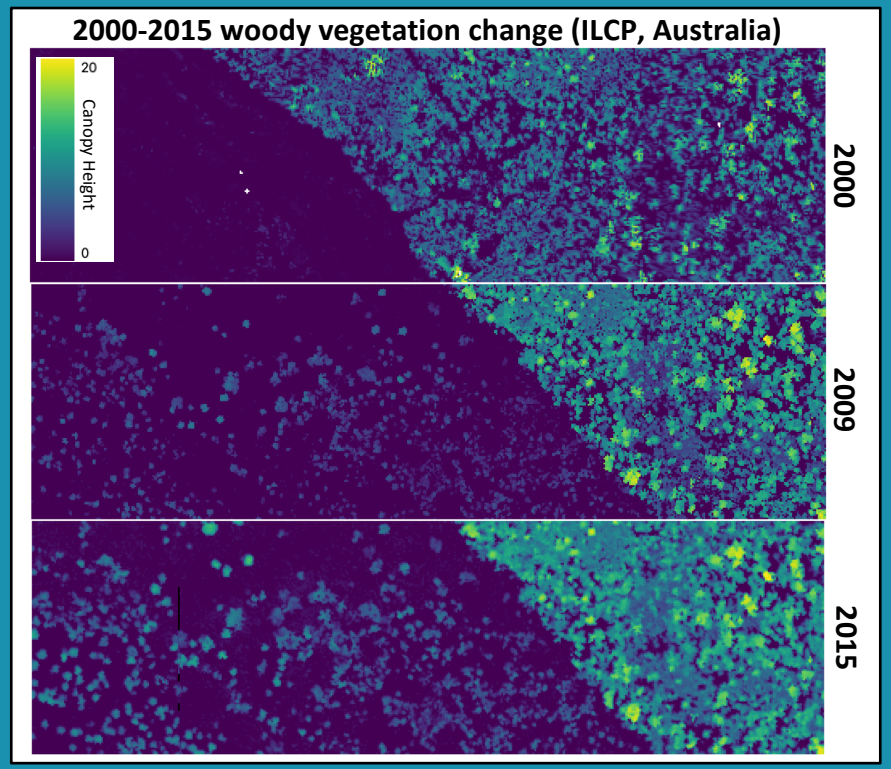


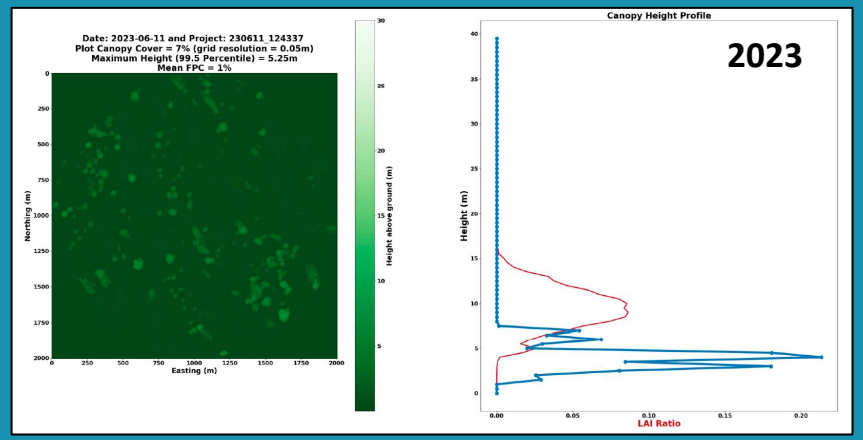
STAKEHOLDER ENGAGEMENT (AUSTRALIA)

- **Queensland Department of Environment and Science:** Increasing interest in verifiable frameworks under “Accounting for Nature” type frameworks, such as the Queensland Land Restoration Fund; and lowering measurement error for Australia’s Emission Reduction Fund
- **Joint Remote Sensing Research Program (University of Queensland, Brisbane)**: Responding to the increasing number of landholders, private organizations and NGO’s interested in biomass change → *Prototype products and field & airborne campaign in May / June 2024*



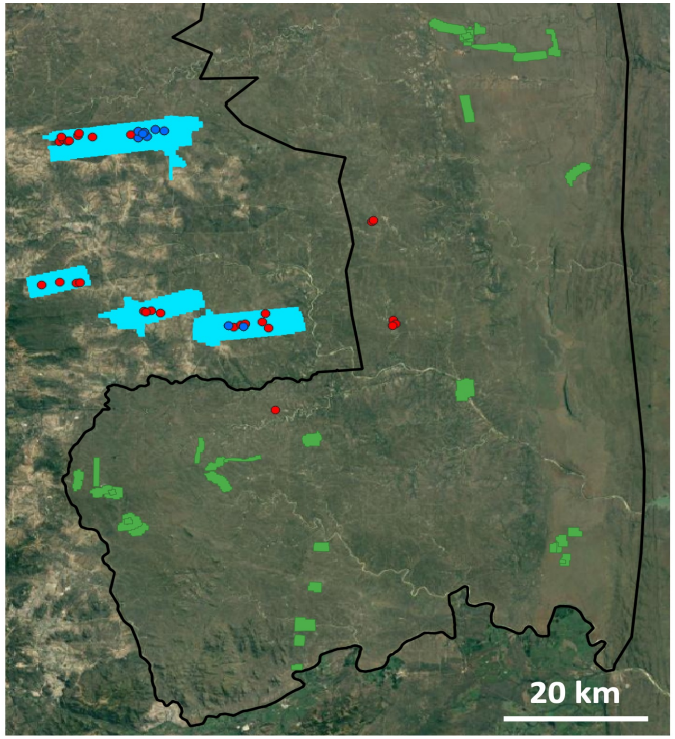
Queensland Department of Environment and Science (2023)





FUTURE DIRECTIONS

- **Fusion of NASA GEDI and ICESat-2 to expand applicability of spaceborne lidar observations across savanna woodlands and shrublands**
- **Are we realizing our objective of reducing uncertainty? Benchmarking of biomass estimators in savannas using new training samples (GEDI & ICESat-2) and auxiliary image datasets (RCS & InSAR)**
- **Extension of Generalized Hierarchical Model Based inference (GHMB) with GEDI and USFS collaborators for estimation of biomass change uncertainty**
- **Generation of high-resolution prototype canopy height and biomass change maps using Sentinel-1 and ALOS-2 time-series over each of the pilot sites**
- **Reference change data in savannas are rare – our efforts on new field and airborne campaigns with collaborators and stakeholders are vital for validation of products and estimation of uncertainty at multiple scales but have encountered challenges**
  - Greater Kruger National Park / Lowveld region, South Africa (Oct/Nov 2023)
  - Southern Brigalow Belt Biogeographic Region, Australia (ILCP, May/Jun 2024)



National Aeronautics and Space Administration

NASA CMS CARBON MONITORING SYSTEM

Thank you!

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Project Poster at CMS 2023 Meeting:
Savanna-Bio: Biomass estimation with new spaceborne missions for MRV in Dry Forests and Savannas