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RTAS: A Radiative Transfer Model for Agricultural Strip-Intercropping Structures

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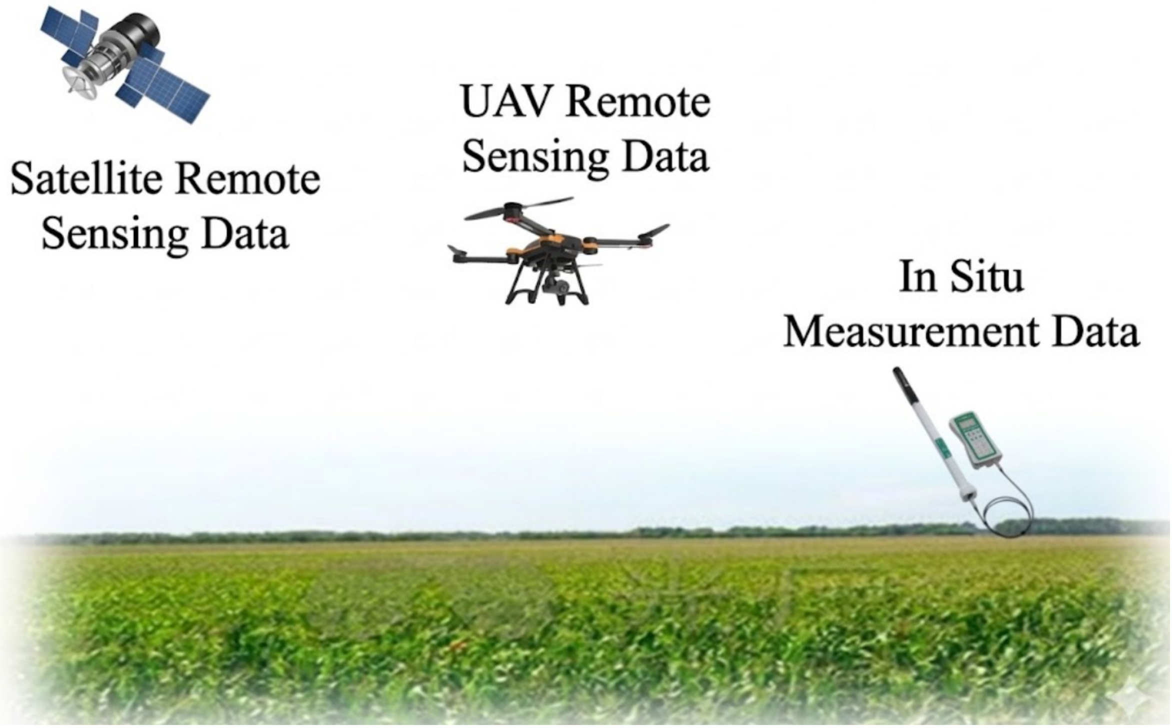
Outline

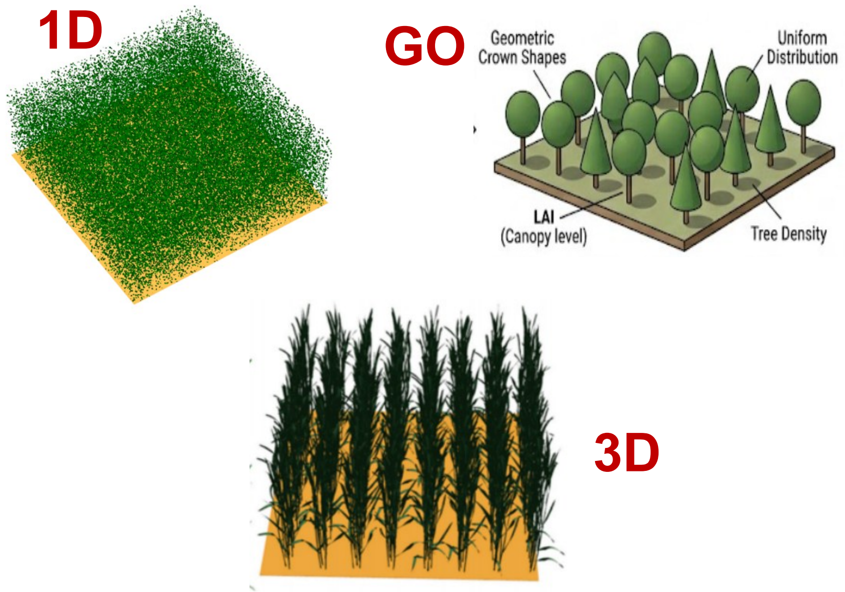
1.1 Background

➢ Strip Intercropping Requires Physical Remote Sensing

- ☐ Alternating maize–soybean strips improve land-use efficiency and production stability
- ☐ Precision management requires Leaf Area Index (LAI), chlorophyll, and canopy structure monitoring
- ☐ However, the canopy is spatially heterogeneous and strongly directional



- **Strip Intercropping: A Mixed Pixel Is Not a Linear Mixture**
  - Adjacent crops differ in height, structure, and optical properties
  - Tall maize casts shadows on soybean
  - Cross-strip scattering changes the reflectance



Model type	Strength	Limitation for strip intercropping
1D RTMs (e.g., PROSAIL)	Efficient	Homogeneous assumption
GO models	Geometry-aware	Weak NIR scattering representation
Spectral Linear Mixture (SLM)	Simple baseline	Ignores mutual shadowing
3D RT models (e.g., LESS & DART)	Accurate	Accurate but computationally expensive

How can we retain physical realism while keeping analytical efficiency?

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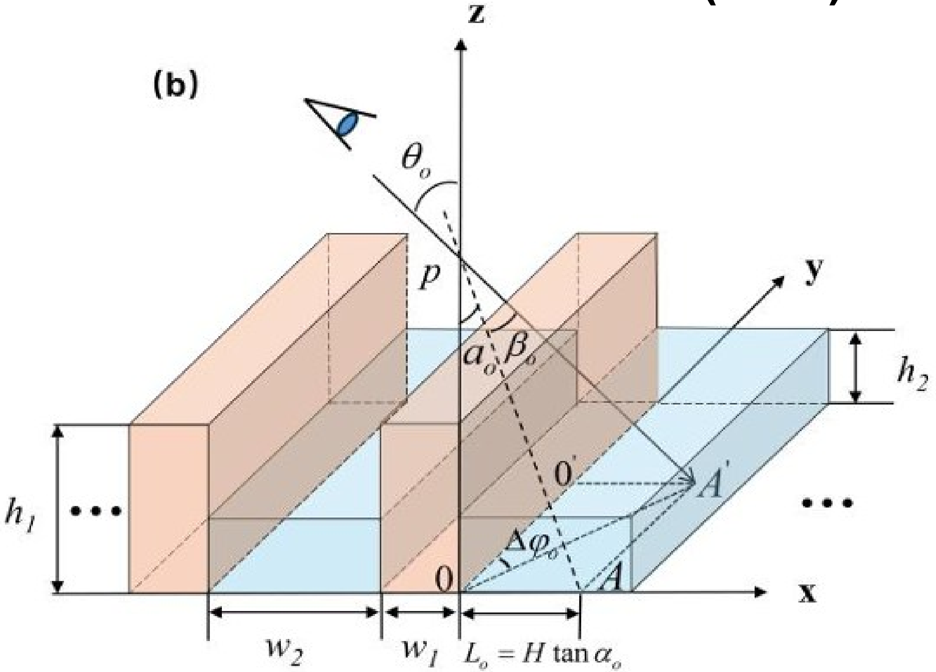
➢ Build A **R**adiative **T**ransfer Model for **A**gricultural **S**trip-Intercropping Structures （**RTAS**）

—— Simulate Bidirectional Reflectance Factor (BRF) of the Canopies

(a)

(b)



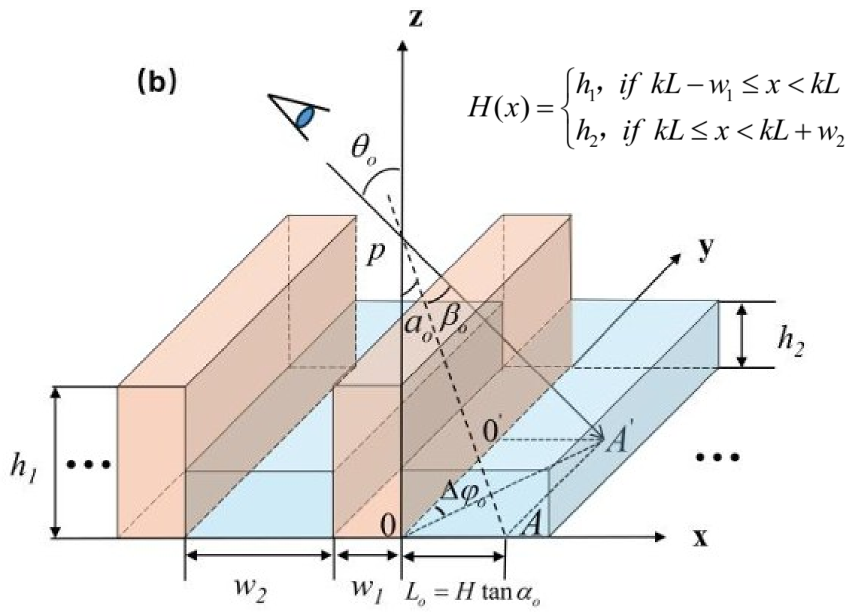
RTAS aims to simulate BRF by resolving

1) How to represent the periodic geometry of the maize-soybean strips?

2) How to account for the complex mutual shadowing and occlusion?

3) How to resolve single and multiple scattering interactions?

2.1 RTAS Modeling



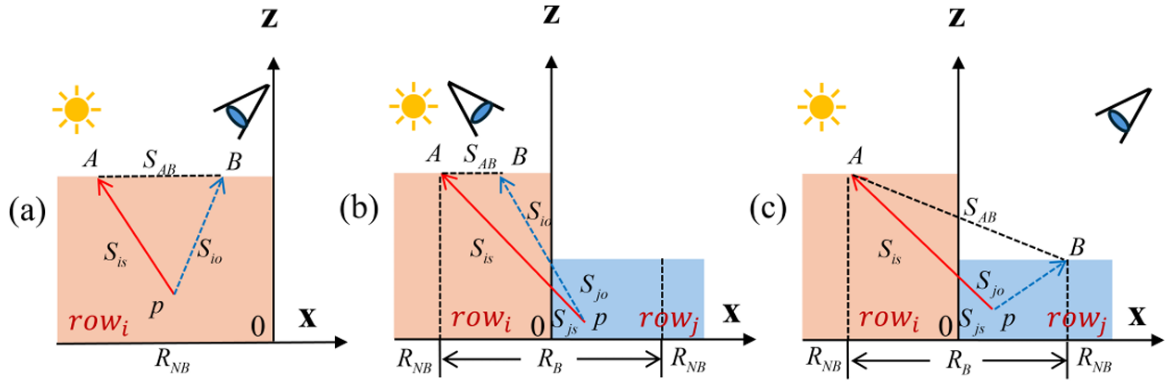
Scene Geometric Definition

- Infinite row direction
- Basic Repeated Unit (BRU): 1 maize + 1 soybean strip
- Row-relative geometry: Controls shadowing

$$\rho(\Omega_s,\Omega_o)=\frac{E_{sun}}{E_{sun}+E_{sky}}\rho^1(\Omega_s,\Omega_o)+\rho^m(\Omega_s,\Omega_o)$$

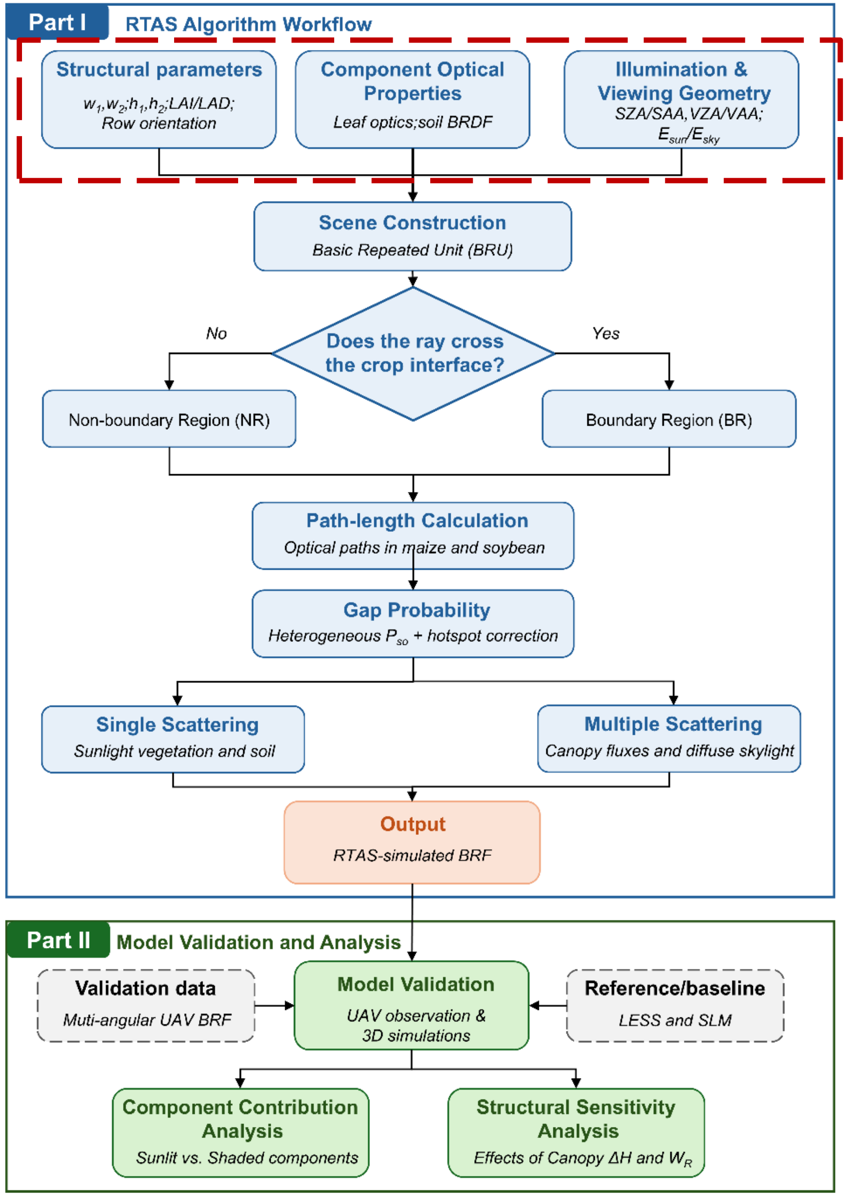
$$\rho^1=\omega(r,t,\theta_l,\Omega_s,\Omega_o)u_L\int_0^H P_{so}(\Omega_s,\Omega_o,z)dz+r_{soil}(\Omega_s,\Omega_o)P_{so}(\Omega_s,\Omega_o,0)$$

$$\rho^m=\frac{1}{E_{sun}+E_{sky}}[\int_0^{H(x)}(uE_+(z)+vE_-(z))P_o(\Omega_o,z)dz+r_{soil}E_-(0)P_o(\Omega_o,0)]$$



Boundary (R_B) and non-boundary (R_{NB}) paths are treated separately

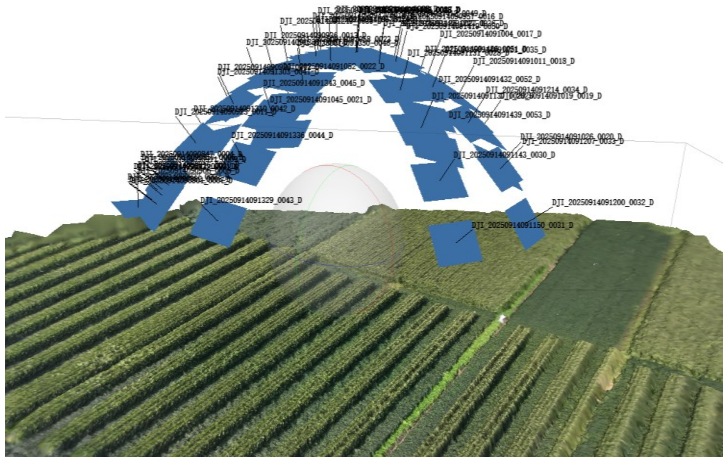
2.2 Research Workflow



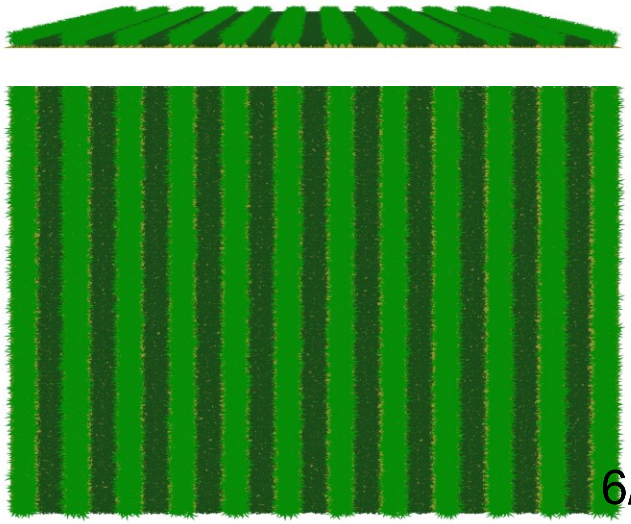
Model's input

- **Validation by Field Measurements**
- **Validation by 3D simulations**

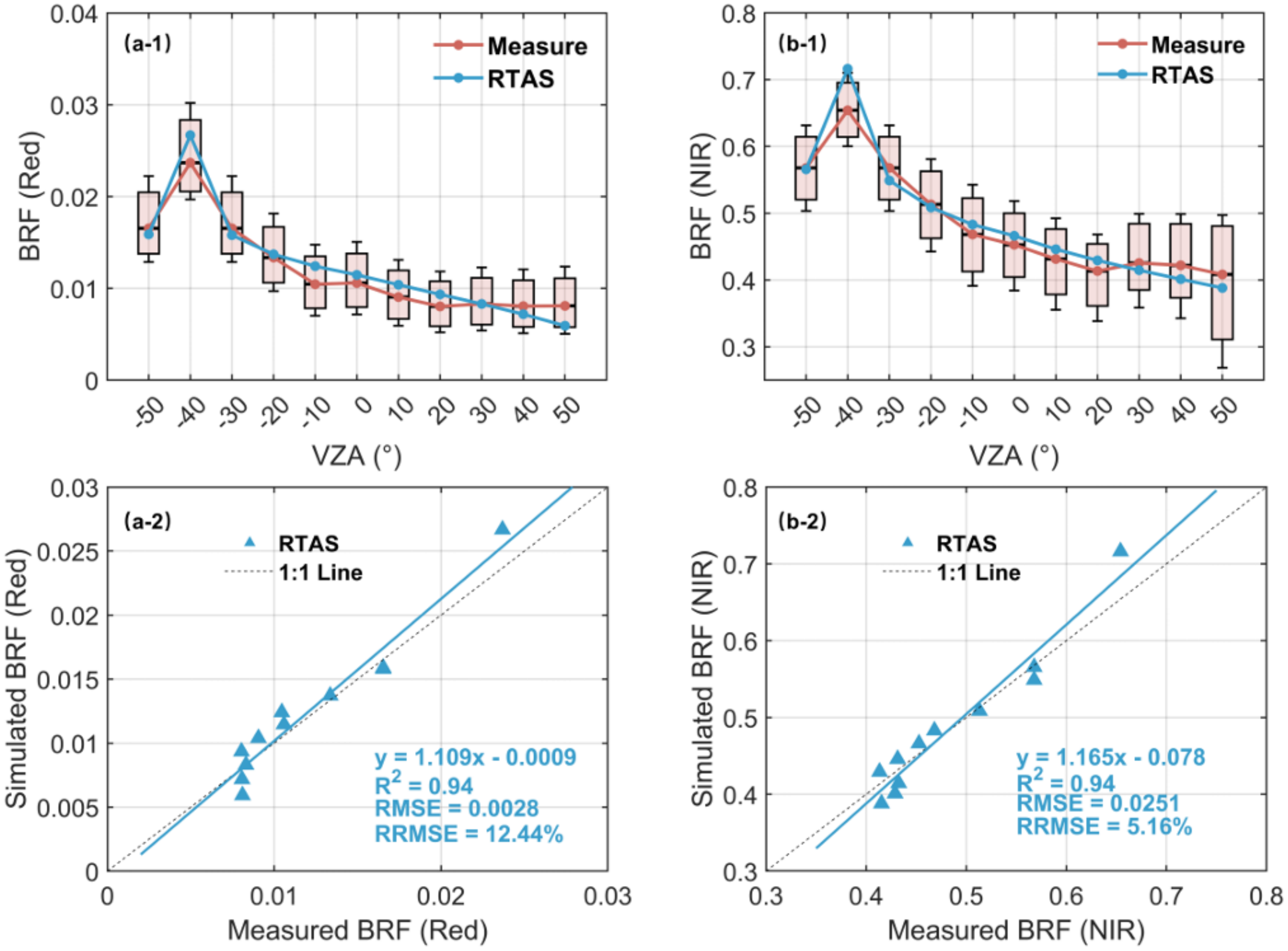
UAV multi-angle observation



3D Scene in LESS software



3.1 Field Validation

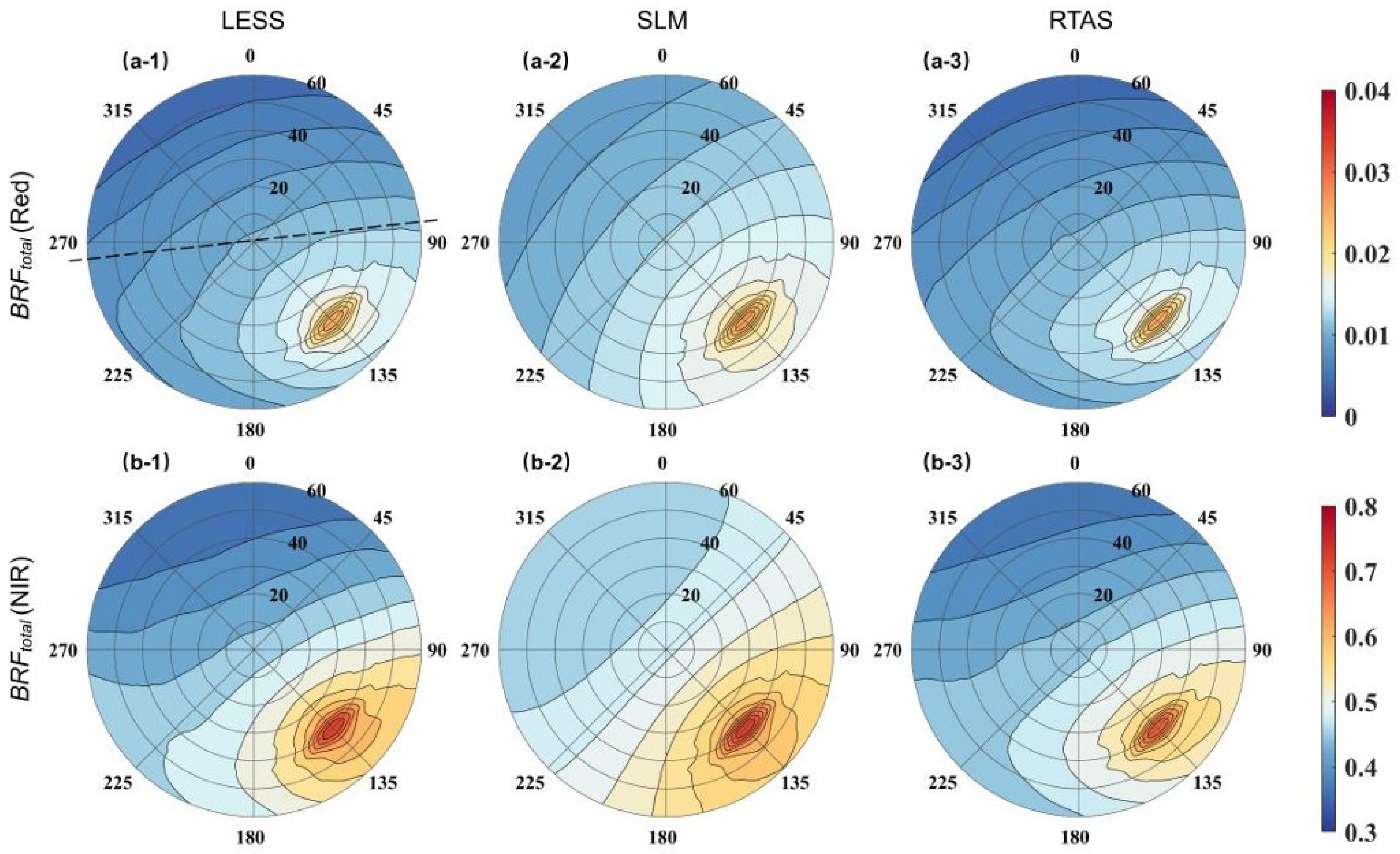


- **Performance:** Accurately captures multi-angular reflectance with an R^2 of 0.94.

- **Anisotropy:** Simulates BRF variation with View Zenith Angle (VZA), with low low *RRMSE* (Red: 12.4%; NIR: 5.1%).

RTAS Reproduces Multi-Angular UAV BRF Patterns

3.2 Comparison with 3D Simulations



RTAS captures the strip-geometry-induced anisotropy observed in LESS simulations

3.2 Comparison with 3D Simulations

◻ RTAS vs. LESS:

Near-perfect agreement in total BRF $R^2 > 0.98$,

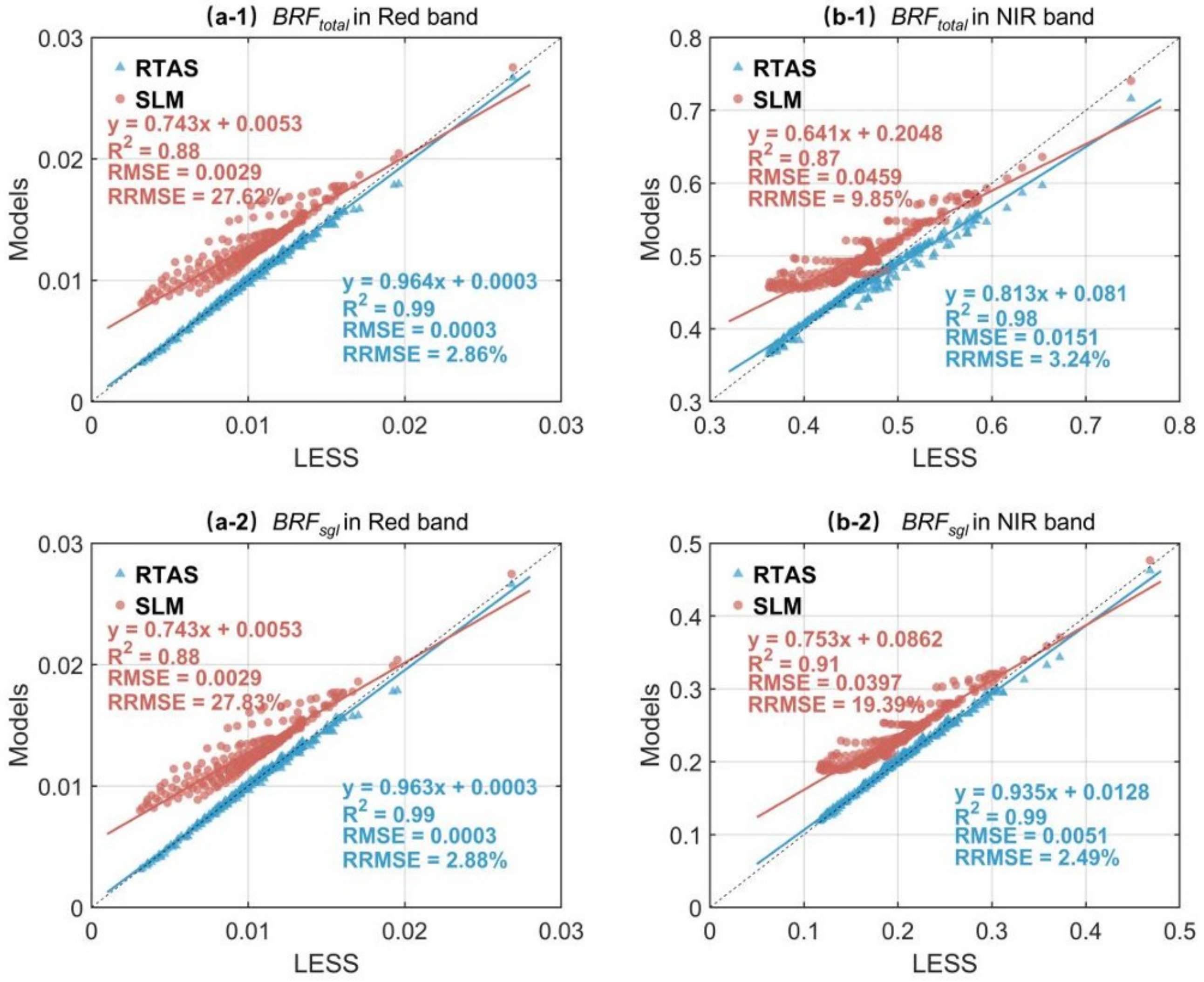
RRMSE < 3.24%

◻ RTAS vs. SLM:

RTAS reduces systematic bias;

SLM shows significant dispersion and bias, with

RRMSE exceeding 27% in heterogeneous scenarios.



RTAS shows high quantitative agreement with LESS

3.3 Geometry–Radiation Decoupling

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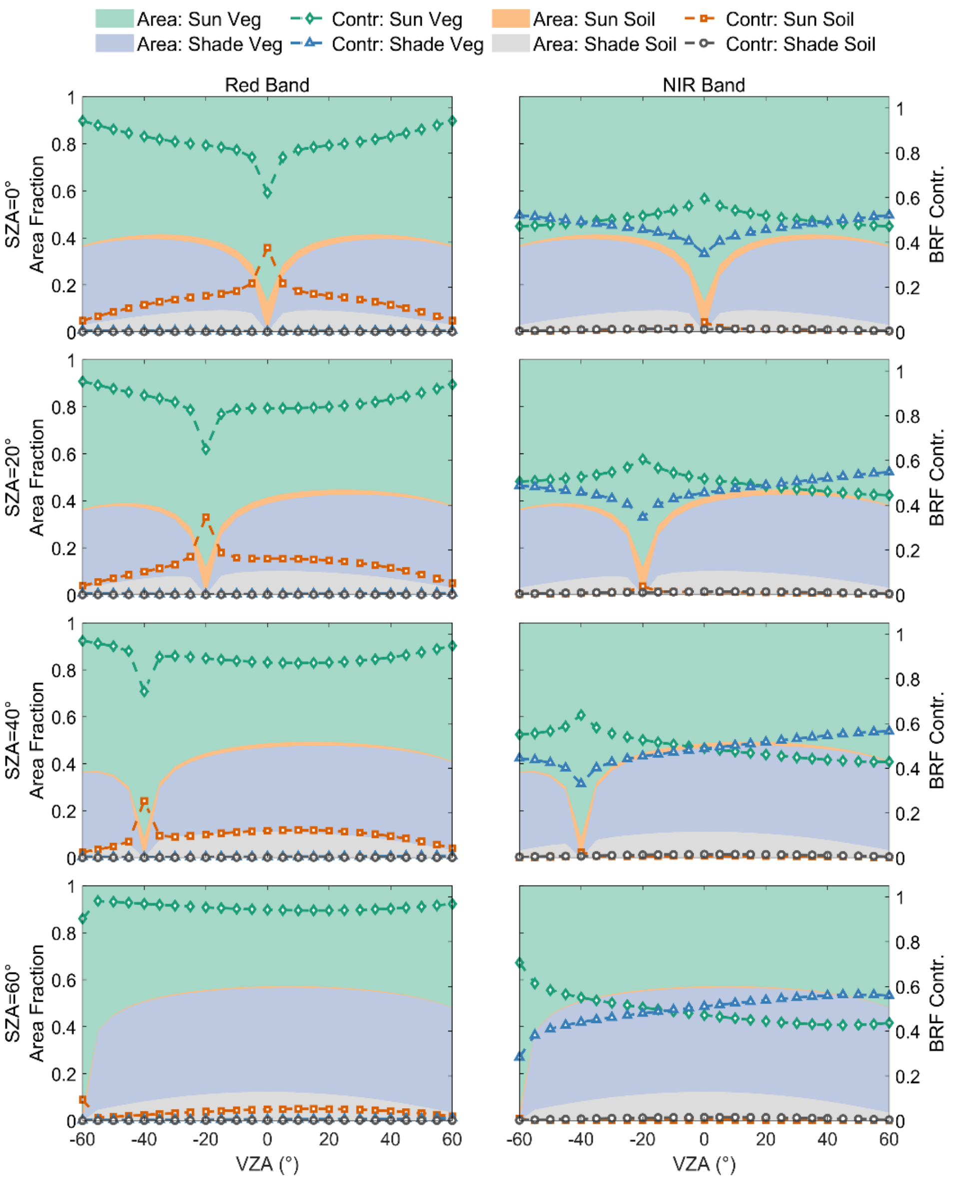


☐ Red Band (Geometric Control):

✓ Dominated by sunlit vegetation due to strong leaf absorption.

✓ Radiance aligns directly with the geometric area fraction.

☐ NIR Band (Multiple Scattering):

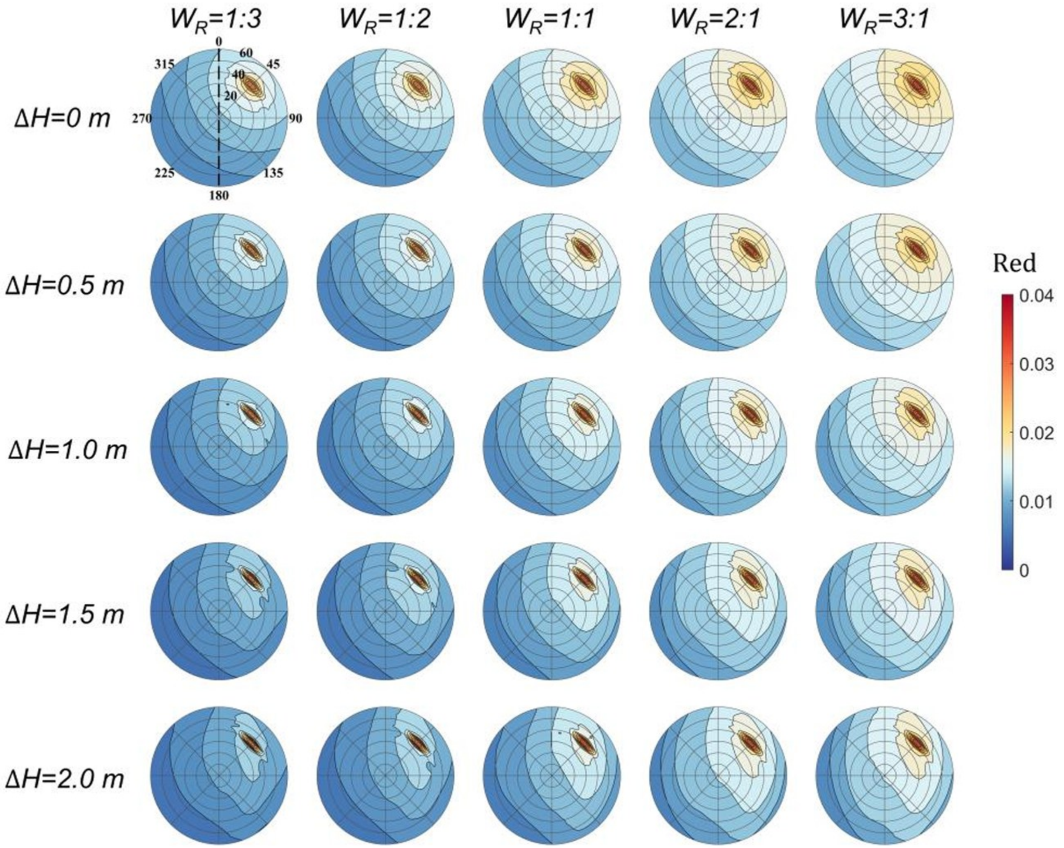
✓ Multiple scattering compensates for energy loss in shaded areas.

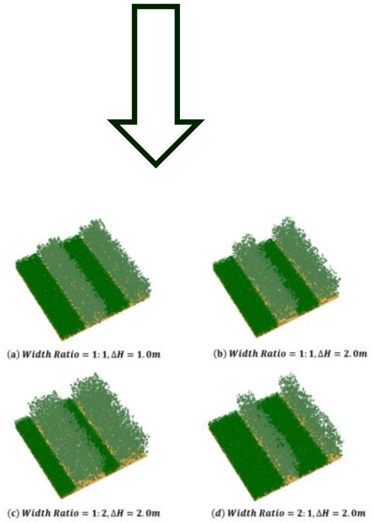
✓ Shaded vegetation remains a substantial contributor to the BRF due to strong leaf scattering.

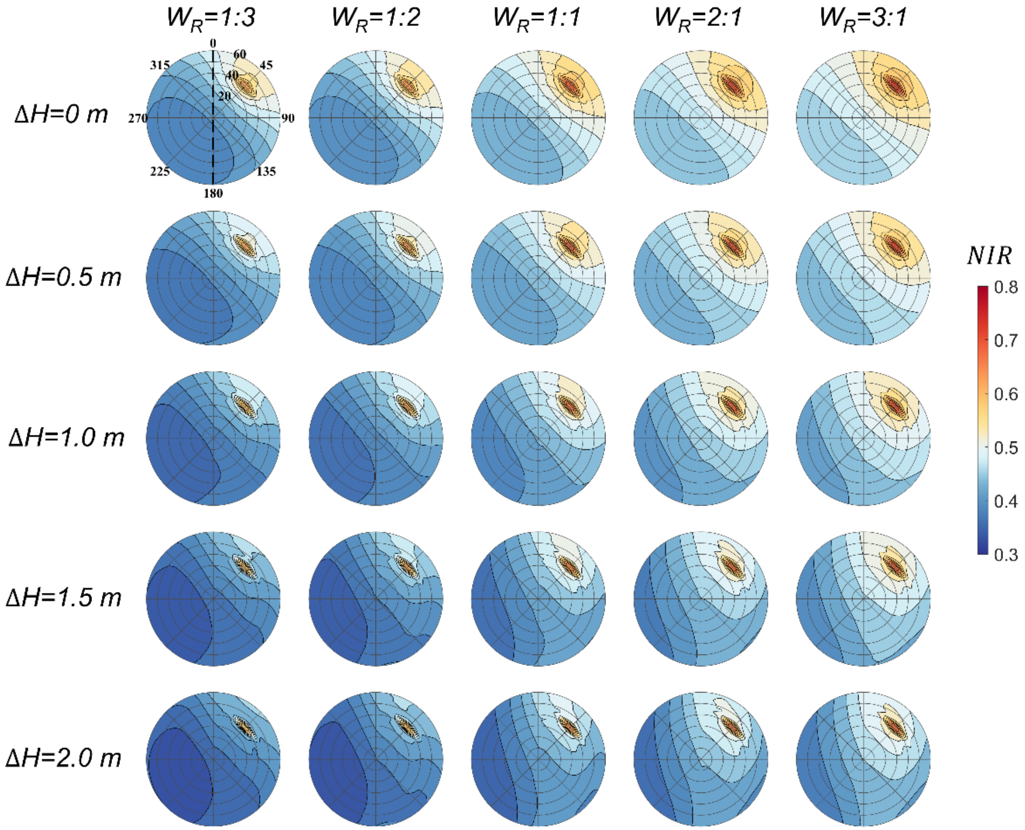
Multiple scattering in the NIR band decouples BRF from pure geometric area fractions

3.4 Structural Heterogeneity

Different structural configurations







Height differences drive BRF asymmetry via shadowing, while width ratios modulate this structural heterogeneity

3.5 Structural Sensitivity

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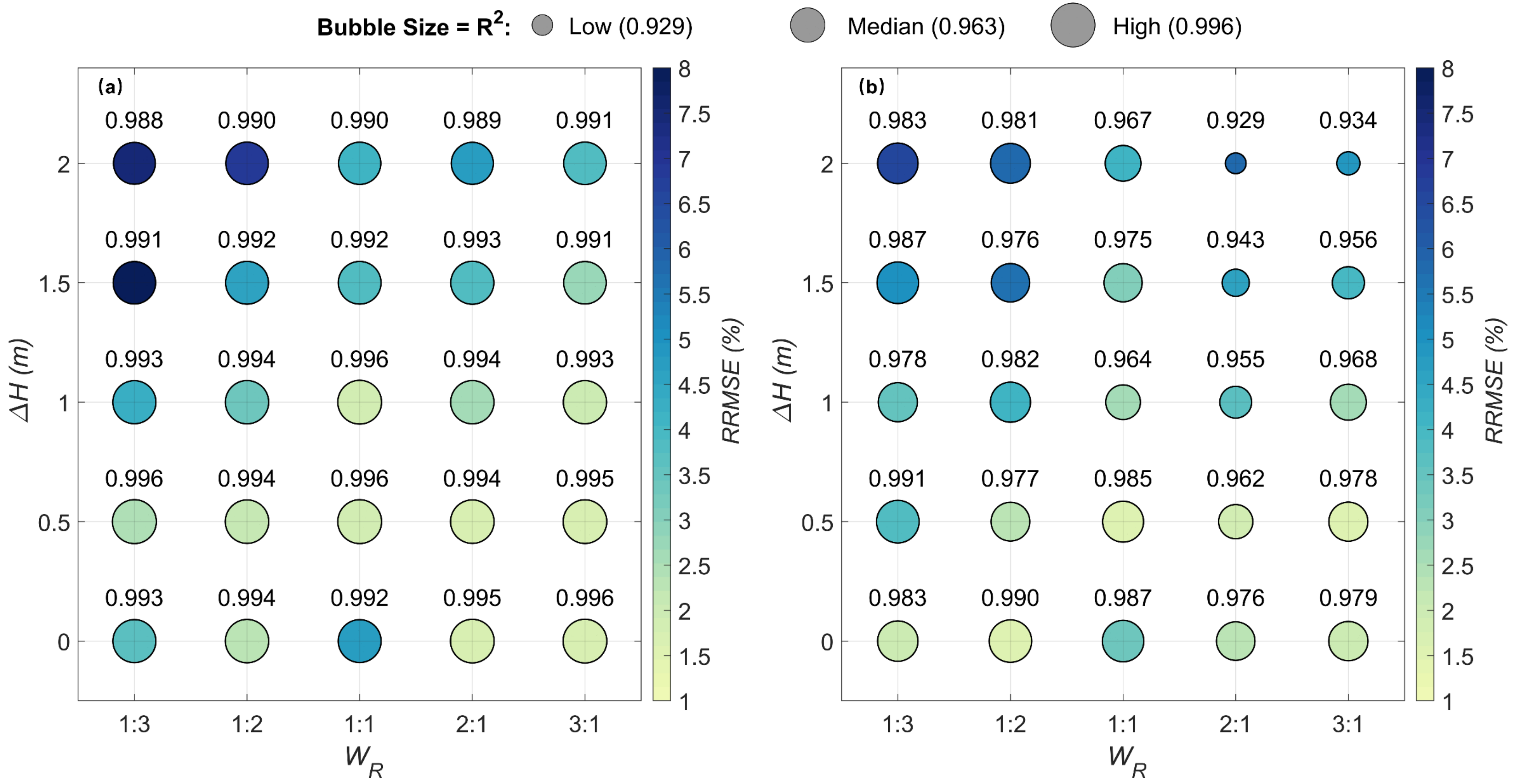

RTAS remains robust under different strip-intercropping structures

Efficient Analytical RTM:

RTAS provides a fast simulation framework specifically for agricultural strip-intercropping.

Superior Accuracy:

RTAS substantially outperforms SLM models by correctly resolving complex inter-strip shadowing and scattering.

Periodic Boundary Conditions:

RTAS enables realistic representation of infinitely repeating strip systems, capturing global canopy patterns.

Future Retrieval Framework:

RTAS supports high-accuracy LUT generation and inversion for LAI, chlorophyll, and SIF for agricultural strip-intercropping

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Thank you！

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