Developing crop specific algorithms to derive accurate GAI and Chlorophyll Content from SENTINEL-2 data: 4D modeling & machine learning

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LPS19, May , Milano

OBJECTIVES

- Decision tool for sustainable agriculture
  - Optimize nitrogen/water application in time and quantity at low cost
  - Satellite monitoring + Data assimilation in crop functioning models for decision support
  - Context = BELCAM project- BELgian collaborative Agriculture Monitoring at parcel level for sustainable cropping systems

- Questions
  - Can generic algorithms (e.g SNAP toolbox) be applied for LAI and leaf Chlorophyll content estimation?
  - Which LAI do we estimate the best?

LAI definitions

Depend on the application/user needs

- Biomass allocation/allometric approach: LAI

  half the total developed area of leaves per unit horizontal ground area (Chen and Black, 1992)

- Transpiration/Photosynthesis: GAI (Green area index):

  all the green vegetation elements including leaves, stems or all other organs

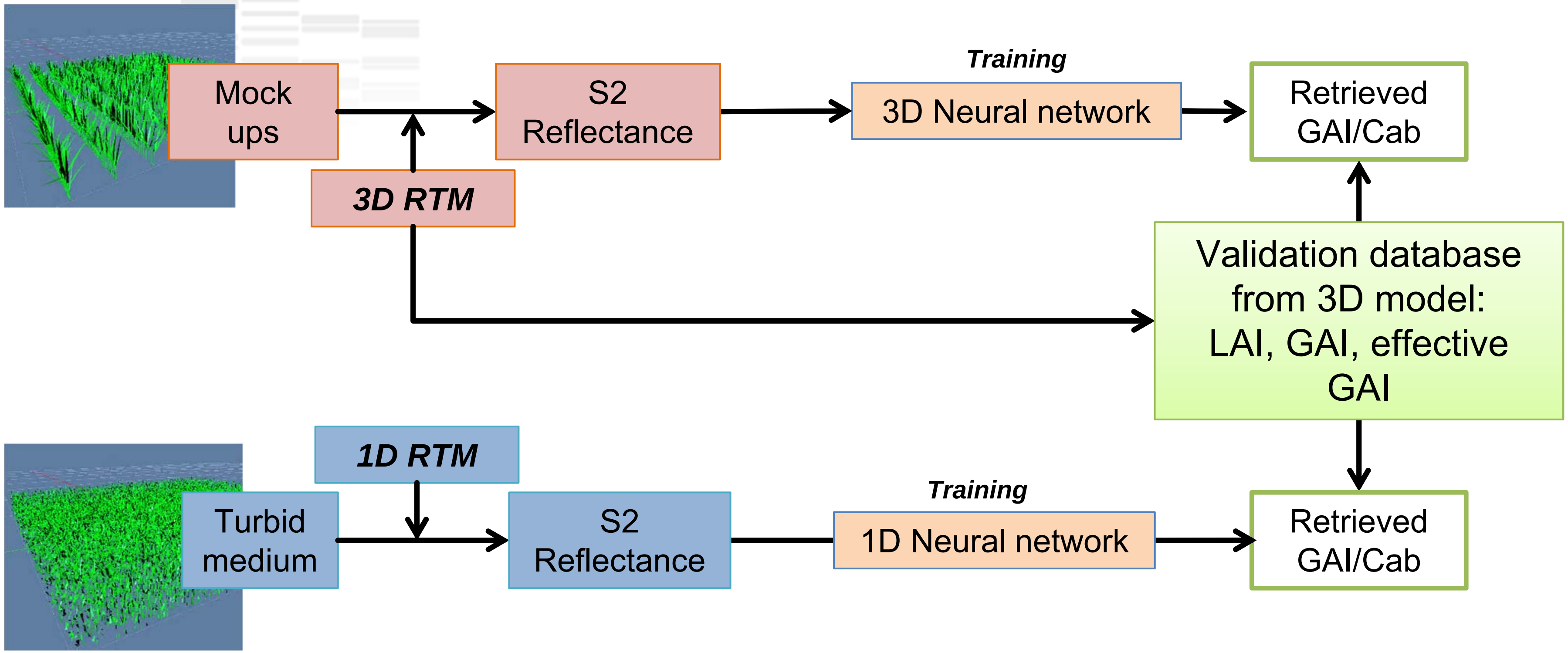
- Radiation interception efficiency:

  spatial arrangement between elements need to be taken into account (clumping): effective GAI

- Rainfall interception efficiency: Plant Area Index (PAI) or effective PAI

  all the vegetation elements including leaves, stems or all other organs, either green or senescent

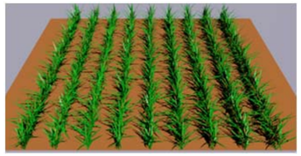
Compare Generic vs Specific: synthetic data set

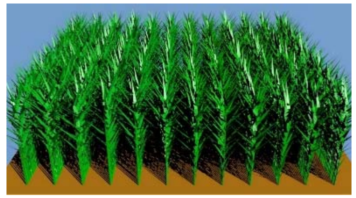


Jiang et al, 2019b, RSE, submitted

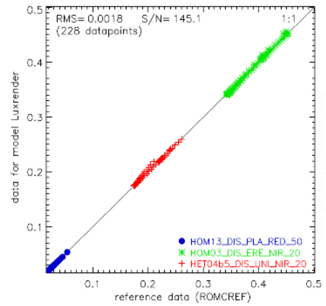
The crop specific algorithm – 3DRTM simulations

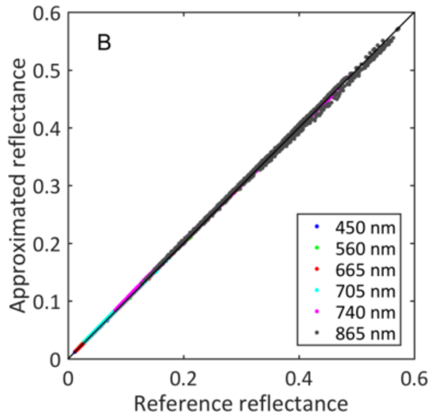
- 4D Mock-ups (3D architecture growth)
  - ADEL-WHEAT
  - Maize (Lopez-Lozano et al, 2007)





- RTM simulations
  - PROSPECT: optical properties
  - LuxCoreRender: ray tracing
  - Validation with ROMC
  - Fasten computation:
    - Decoupling soil/vegetation layers
    - Use the total absorption coefficient





Jiang et al, 2019a, RSE, in revision

The specific algorithm – 3DRTM simulations

Plant density
Phillochron
Leaves (number/size/inclination)

WHEAT
Tillers (inclination/number)

MAIZE
Inter-Row Width

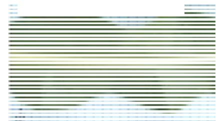
650 wheat + 650 maize

Optical Prop.

BRIGHTNESS

Soil Spectra (x5)

PROSPECT



LuxCoreRender
OPEN SOURCE PHYSICALLY BASED RENDERER

S2 reflectances
Nadir
4 SZA
5 SAA

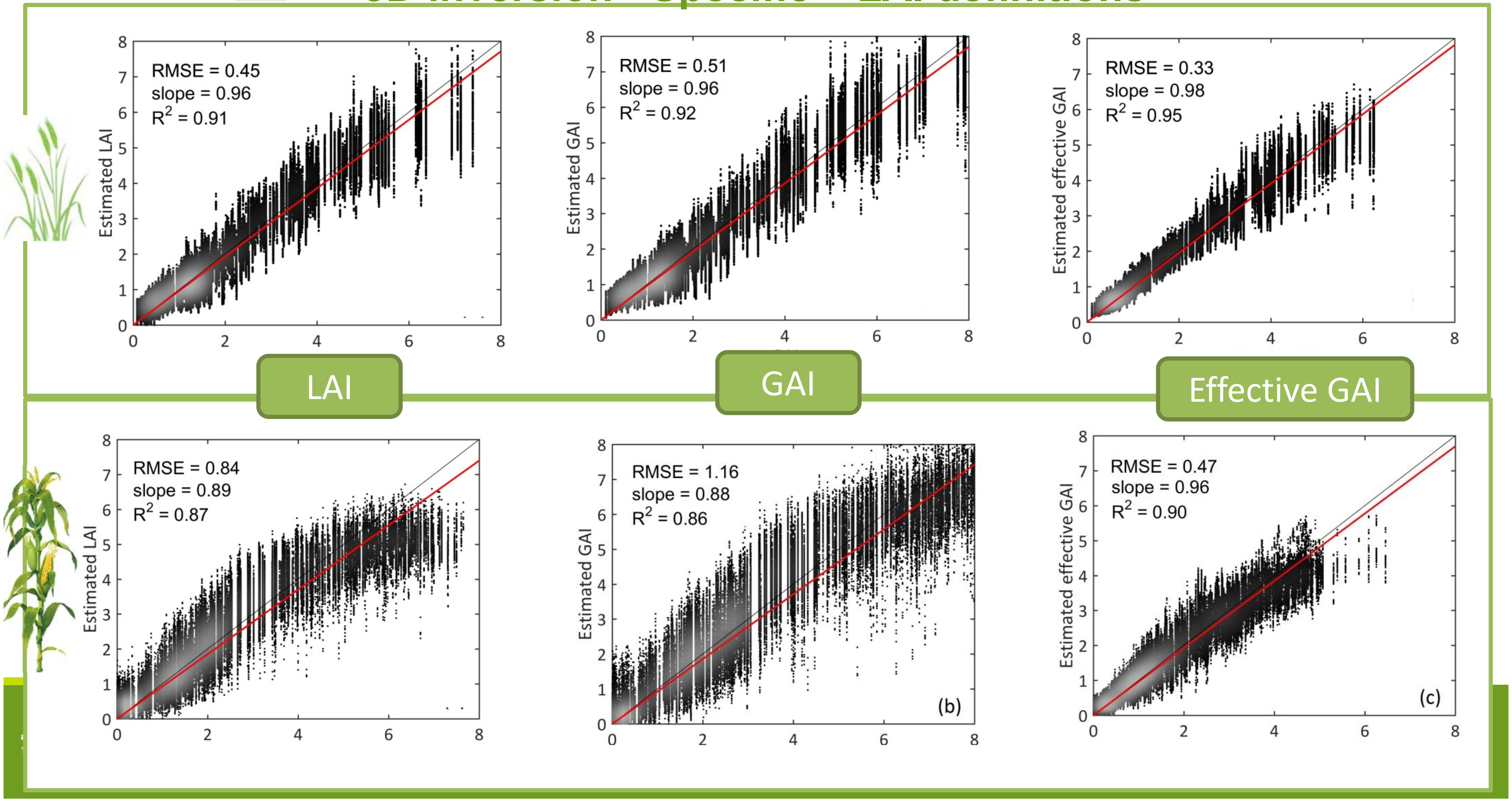
Leaf optical properties	Refractive Index n	1.4					
	Mesophyll, N	1.5					
	C_{ab}(µg.cm^{-2})	20	90	45	30	5	Gauss
	C_{dm}(g.cm^{-2})	0.003	0.011	0.005	0.005	5	Gauss
	C_{w}_Rel	0.6	0.85	0.75	0.08	5	Uniform
	C_{bp}	0.0	2.0	0.0	0.3	3	Gauss
Soil background	B_s	0.5	3.5	1.2	2.0	5	Gauss

The generic algorithm (SNAP toolbox)

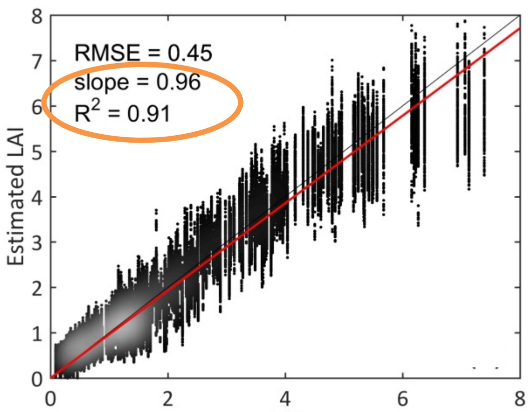
- Similar to the CYCLOPES product at 1km resolution
- Training data base = PROSAIL simulations, 1DRTM
- Distribution in agreement with 3D simulations

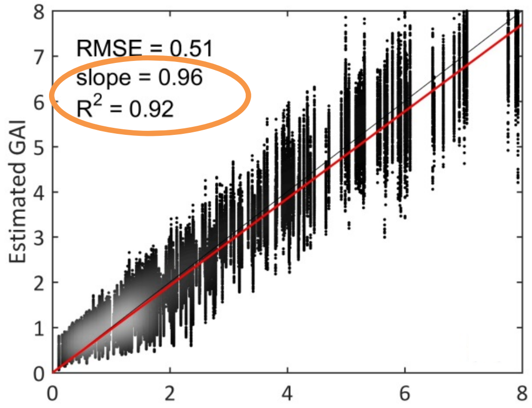
	Input variable	Minimum	Maximum	Mean	Std	Class	Law
Canopy structure	GAI	0.0	8.0	2.0	3.0	6	Gauss
	ALA (°)	30	70	45	30	3	Gauss
	hotspot	0.1	0.5	0.2	0.5	1	Gauss

3D inversion - Specific – LAI definitions



3D inversion - Specific – LAI definitions

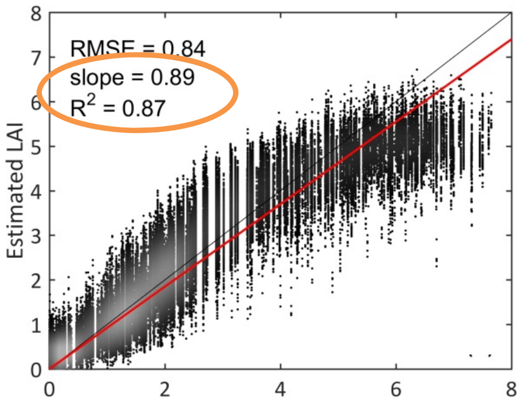


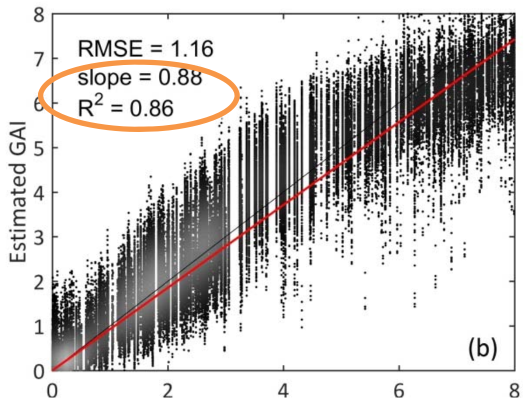


LAI

GAI

- Same R^2 and slope
- Higher RMSE, mainly due to the stems

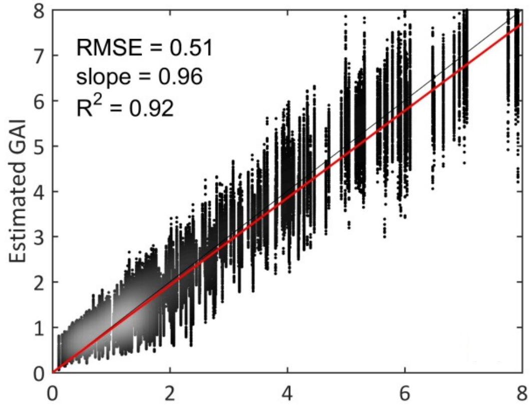


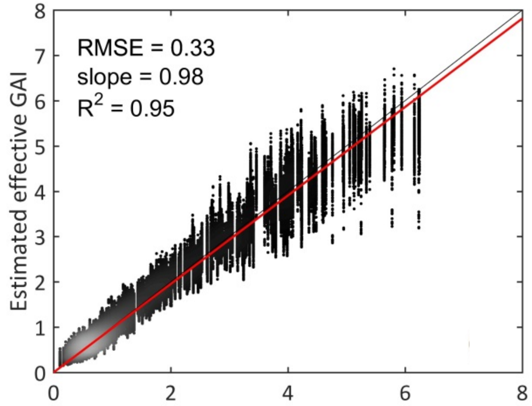


- Systematic underestimation high values = saturation

3D inversion - Specific – LAI definitions

- Effective GAI better estimated
- No bias





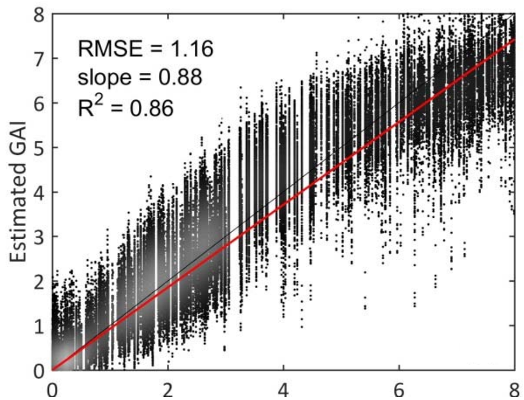
GAI

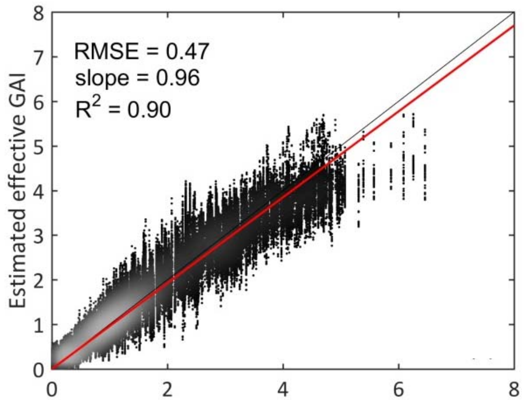
Effective GAI

- Saturation

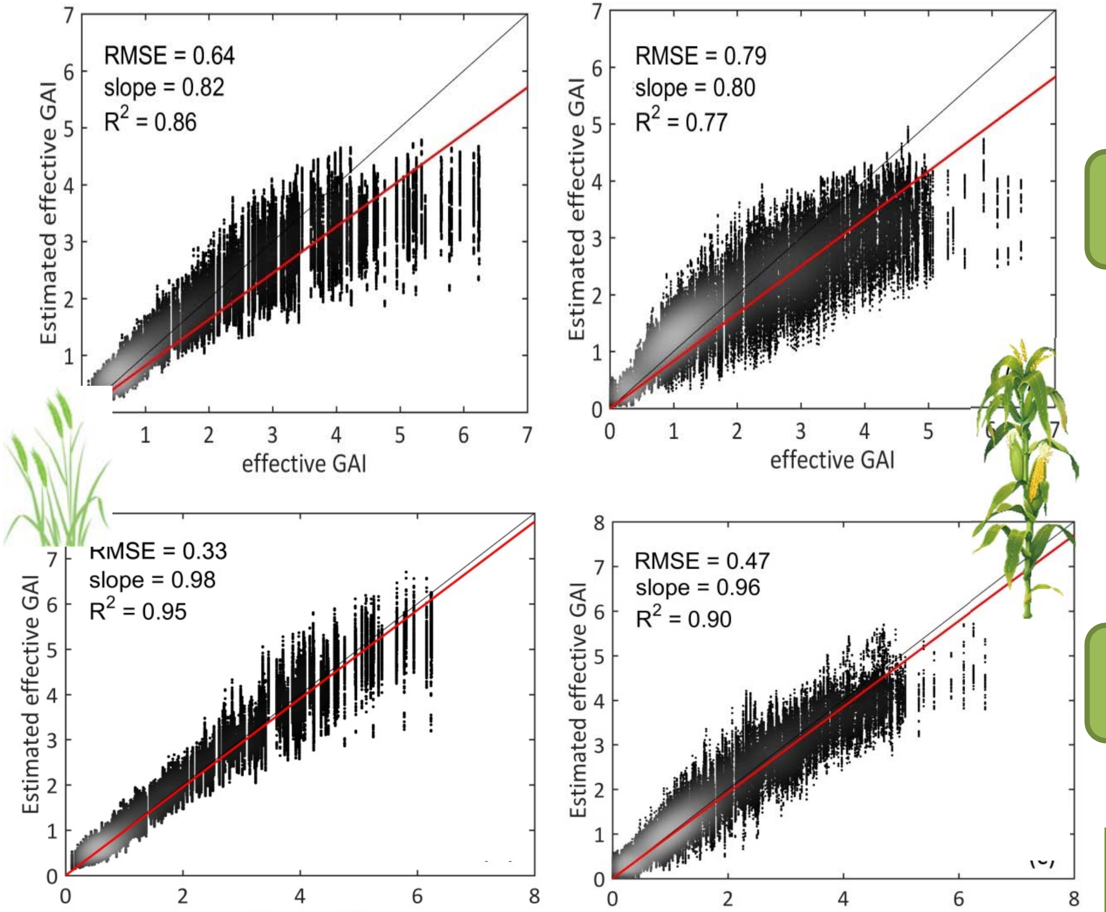
(improve training data base)

- Wheat better estimated than maize





Crop Specific (3D NN) vs Generic (1DNN): effective GAI

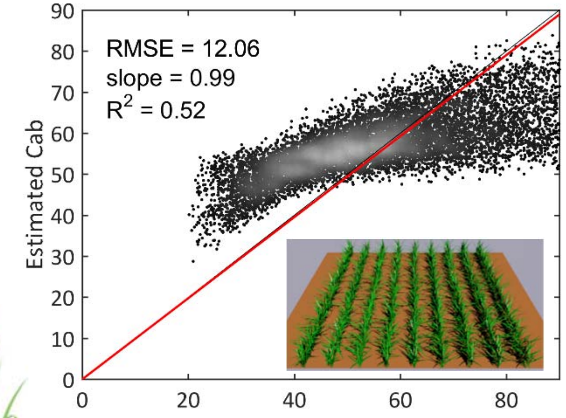


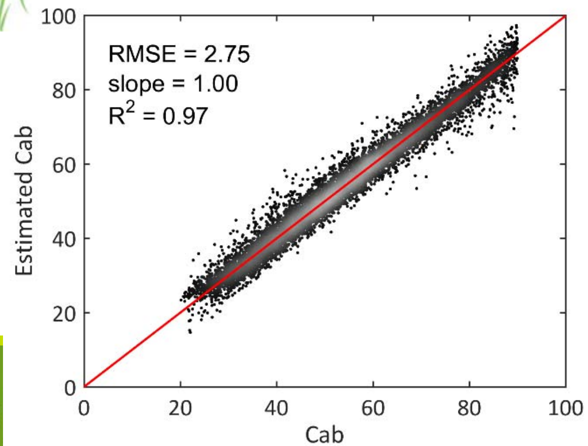
1D Inversion

3D Inversion

- 3D model provides better accuracy
- Less sensitive to sun position /row direction

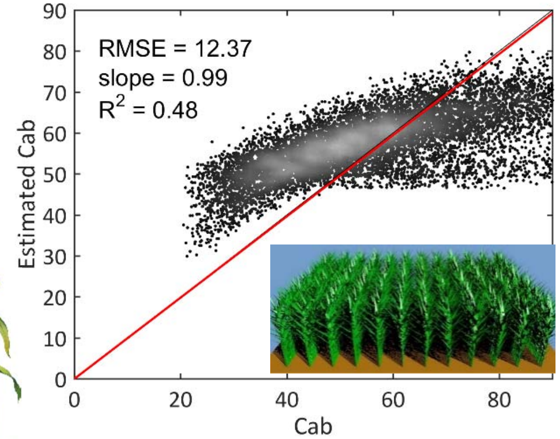
Generic vs Specific – Cab: comparison over simulations

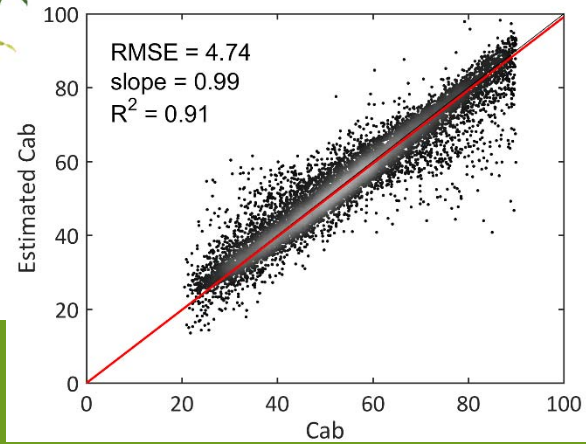




1D Inversion

3D Inversion

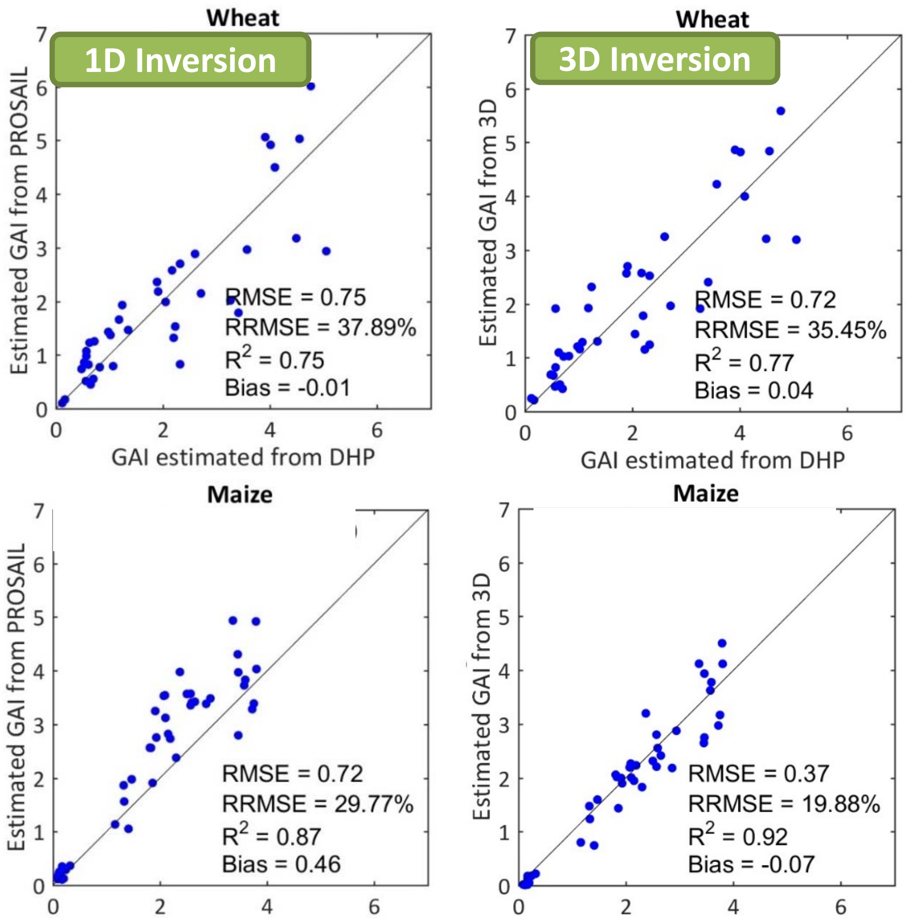




Validation against ground data

- P2S2 (see poster #222, Friday)
  - SENTINEL2
  - Digital Hemispherical Photographs, wheat (43) + maize (45)
  - SPAD

Generic vs Specific – effective GAI – P2S2 dataset



- Similar results on wheat
- Significant improvement on maize

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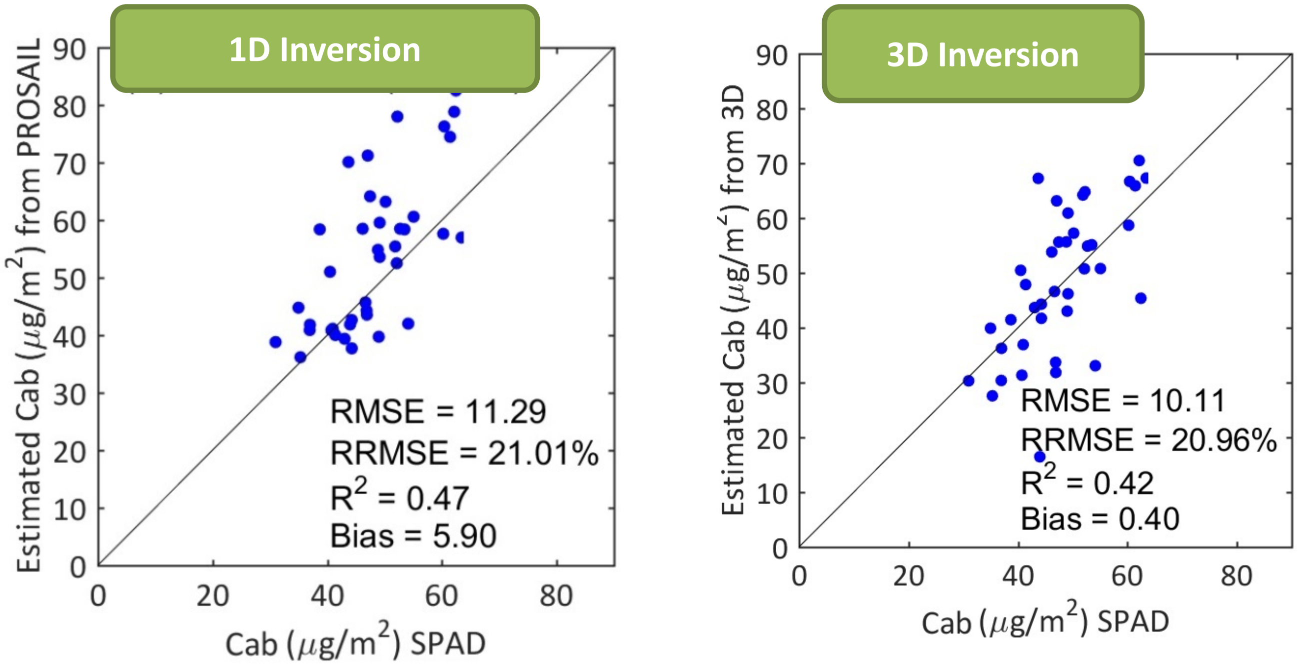
Generic vs Specific – Leaf chlorophyll– P2S2 dataset



- Significant improvement for 3D simulations
- Need to be confirmed for maize

Conclusions

- 3D model inversion is more accurate
  - Especially for canopies far from the turbid medium assumption
  - 4D mock-ups
    - Growth limited to the period before earing/flowering
    - Other species?
- Effective GAI is better retrieved
  - PAI not investigated yet (not enough senescence)
  - To be accounted for in crop functioning models, process modeling
- Future work
  - Continue validation
  - Investigate data driven approach (machine learning)