Coupling 3D radiative transfer models with soil vegetation transfer models for sparse vegetation and validating with hyperspectral remote sensing and eddy covariance flux data

Hideki Kobayashi
Japan Agency for Marine-Earth Science and Technology
koba.hidekin@gmail.com

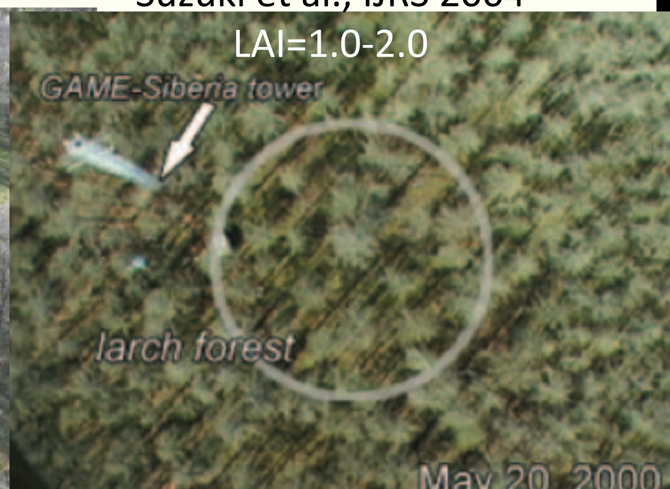
Collaborators:
Dennis Baldocchi (UC Berkeley), Youngryel Ryu (Harvard Univ.), Qi Chen,(Univ. Hawai'i), Siyan Ma(UC Berkeley), Jessica Osuna(UC Berkeley), Susan Ustin (UC Davis)

Introduction

- Most land surface models use 1D canopy scheme
  - Horizontally homogeneous with randomly distributed leaves
  - Computing energy and carbon exchanges.
- This simplified modeling makes it difficult to evaluate the radiation environment in spatially heterogeneous landscapes

Oak savanna, CA (US-Tonzi)

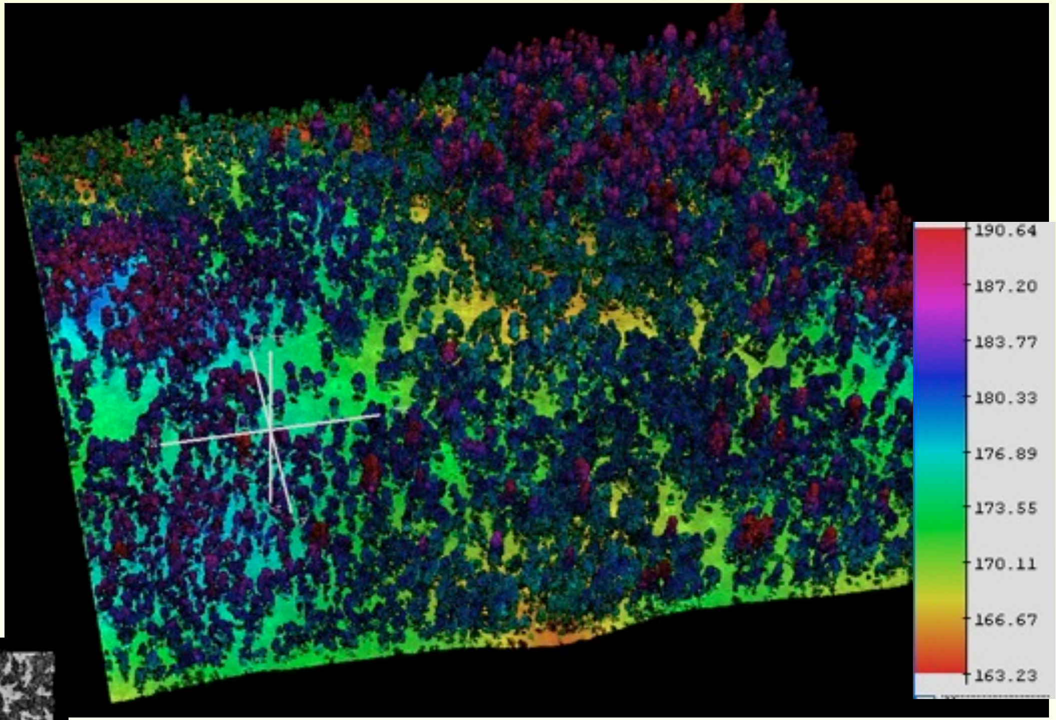
Larch at Yakutsk
Suzuki et al., IJRS 2004

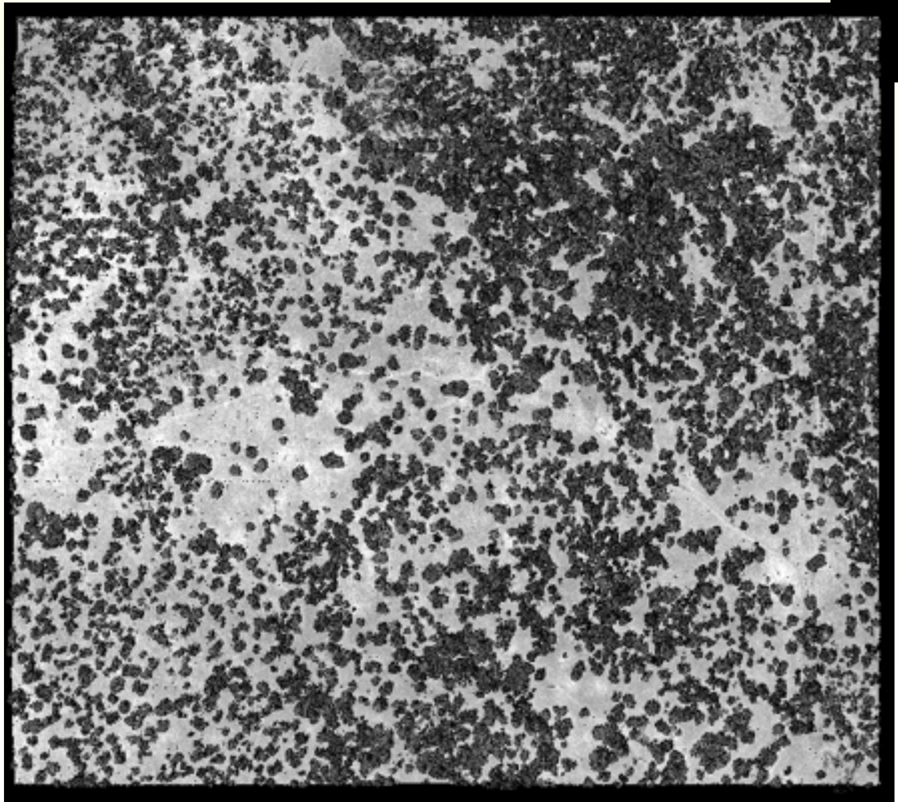


Black spruce, Alaska, May 18, 2011
Sin Nagai and the PEN project

Introduction (cont.)

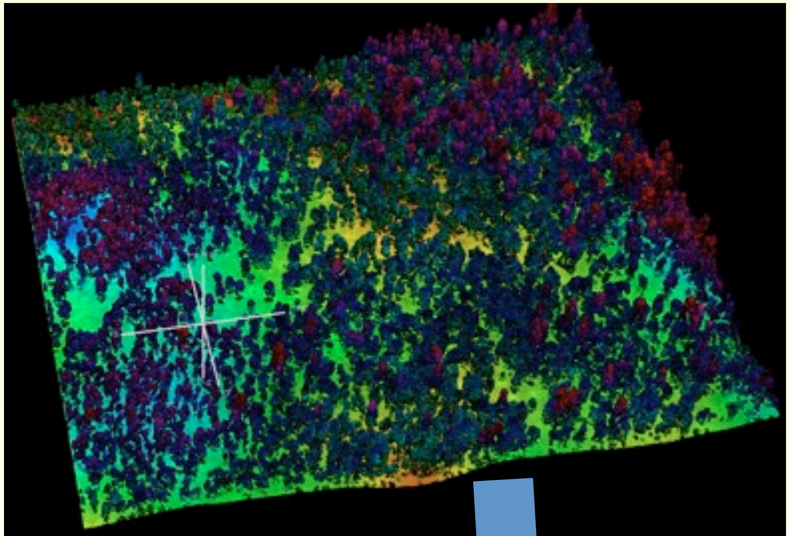
- The 1D models are efficient in computing radiation, energy and carbon fluxes
  - Under current computation, this is the only way to run globally over decades, and couple with the earth system models
  - There are some approaches to consider the 3D effect (clumping index in RT schemes)
- However, it is not easy to quantify where and how we need to include the 3D effect
  - 3D models are useful to find where 1D models give unreliable answers
- Recent LiDAR techniques make it possible to obtain the canopy structure information
  - Canopy heights, tree positions, crown shapes



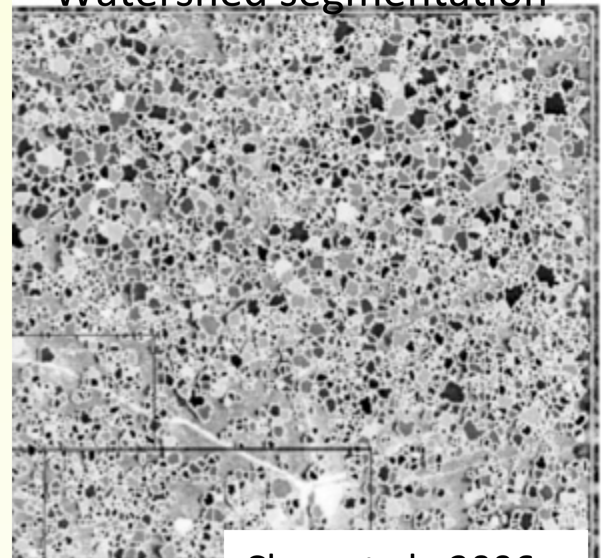


Airborne LiDAR images obtained at the oak savanna site in California.
April, 2009

Tree structure extraction

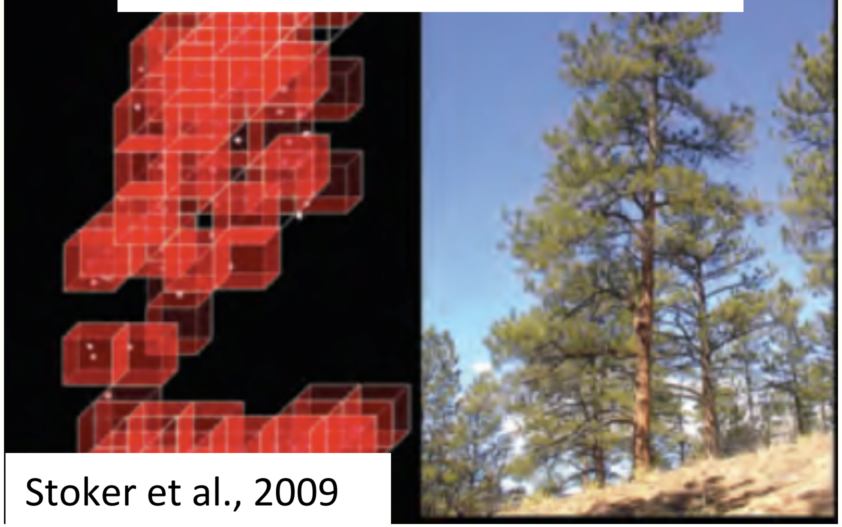


Watershed segmentation

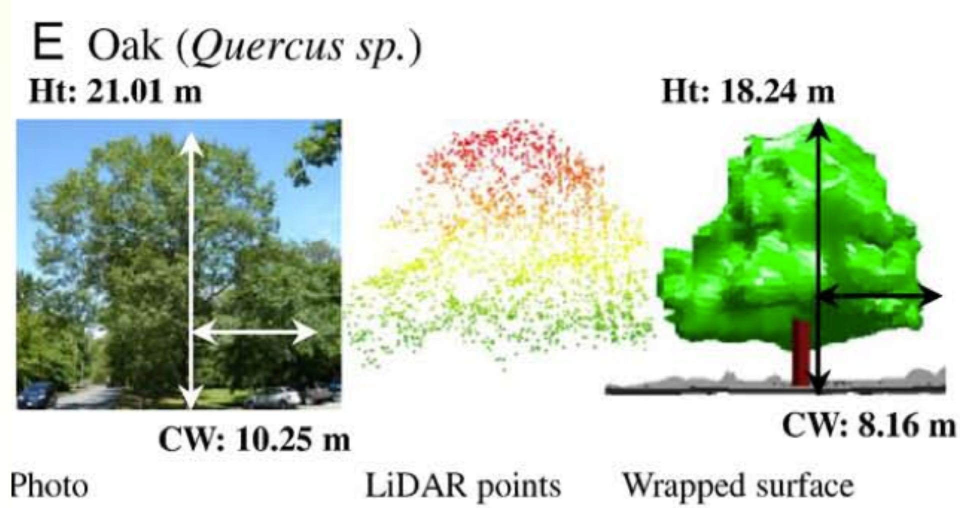


Chen et al., 2006

Voxel representation



Stoker et al., 2009



Kato et al, RSE 2009

Questions

- How can we model the landscape scale spatial variability of radiation and energy budgets in heterogeneous ecosystems?

- Can the 3D approach reduce the uncertainties in simulating energy and carbon fluxes of ecosystems through an accurate characterization of radiation environments?

To answer these questions…

- develop the 3D radiative transfer model (FLiES) coupled with the energy and carbon exchange model (CANOAK)
  - Oak savanna site
  - Airborne LiDAR data, digital photos

- test the performance of 3D model using intensive field measurements

- compare the results from 1D and 3D schemes with the eddy covariance measurements

Study site: Oak woodland

- Foothills of the Sierra Nevada Mountains, Ione, CA, (38.43N, 120.97W)
- LAI=0.72 (Ryu et al., 2010)
- Tree species:

  Blue oak (*Quercus douglasii*)

  Pine (*Pinus sabiniana*)

- Eddy covariance measurement since 2001
- Remote sensing data (AVIRIS, LiDAR etc)
- Traversing radiometer system at understory

Model structure

- Energy exchange model (CANOAK) <- 3D radiative transfer (FLiES)
- Hourly time step

Turbulent transfer

1D turbulence scheme

Ta, water vapor, CO_2

(Lagrangian approach)

Radiative Transfer

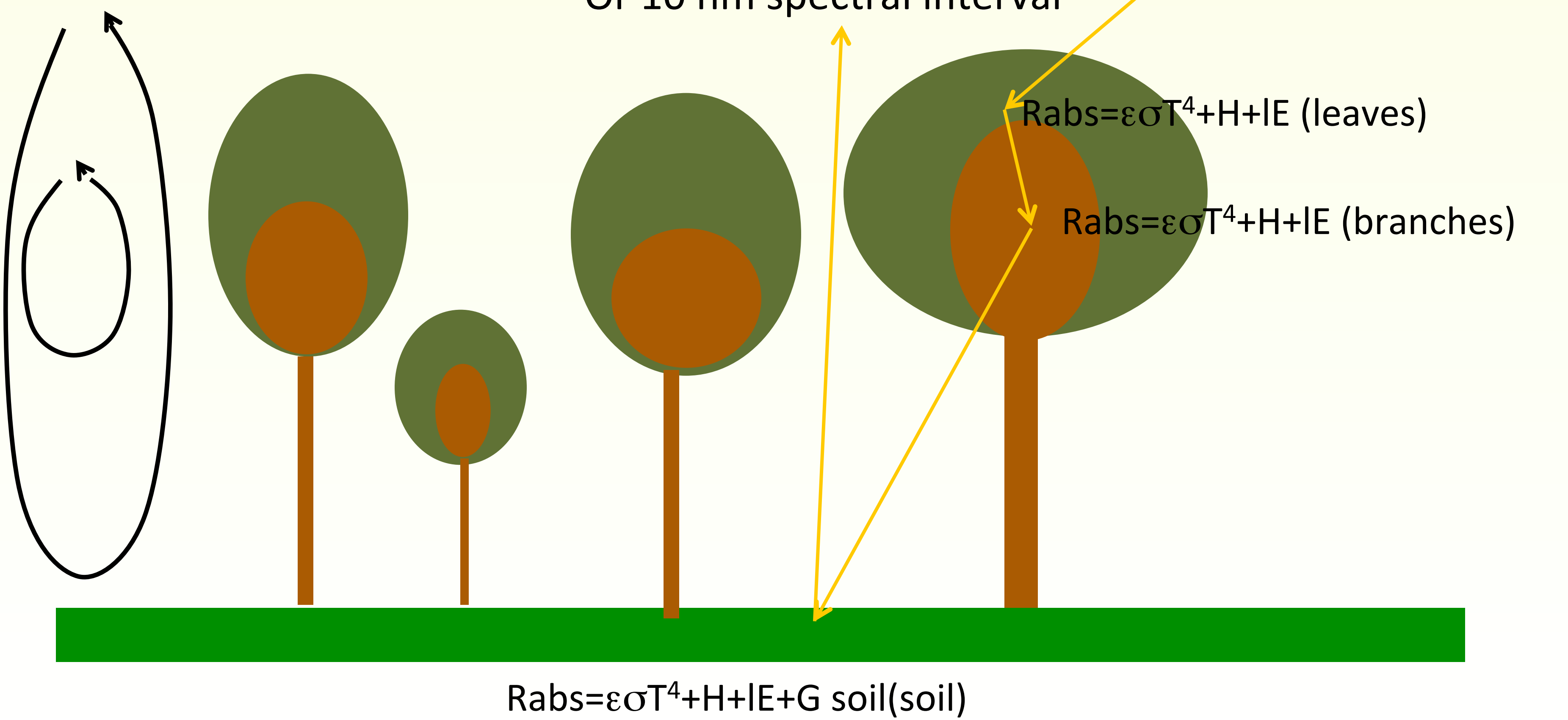
Monte Carlo Ray Tracing

visible (0.4-0.7μm),

near infrared (0.7-4.0 μm)

thermal infrared (8-14.0 μm)

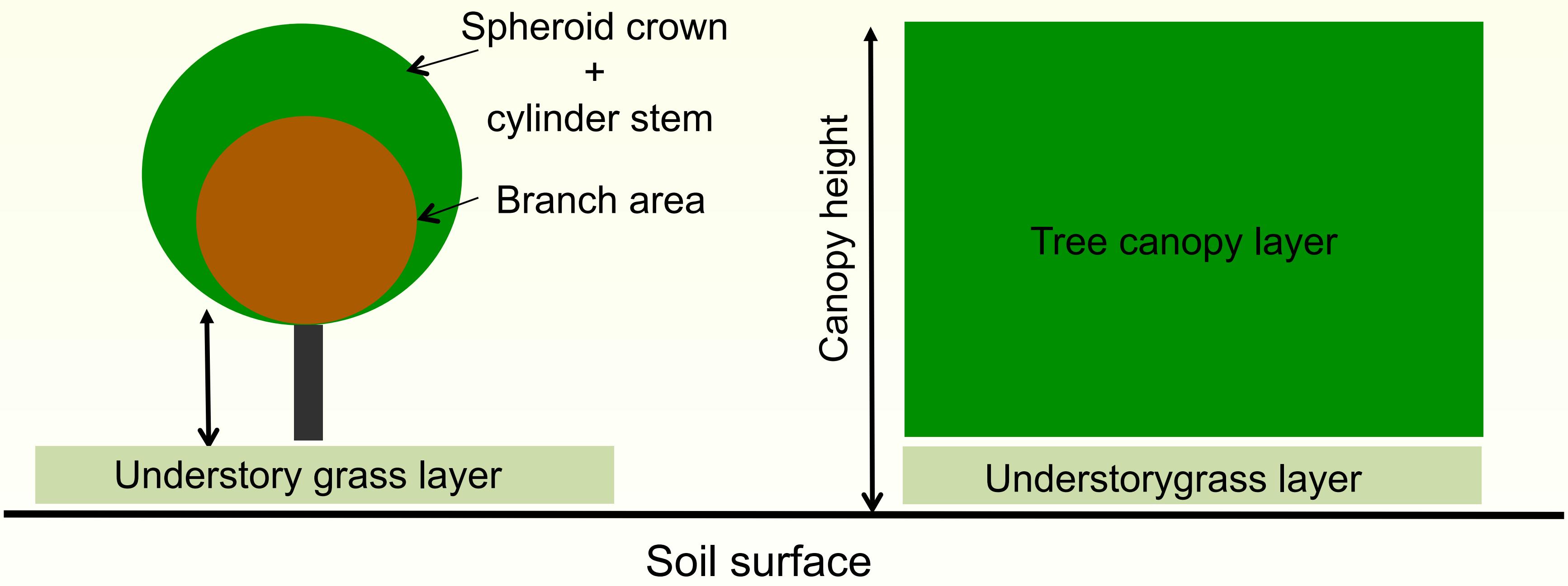
Or 10 nm spectral interval



1D and 3D schemes

3D scheme

1D scheme

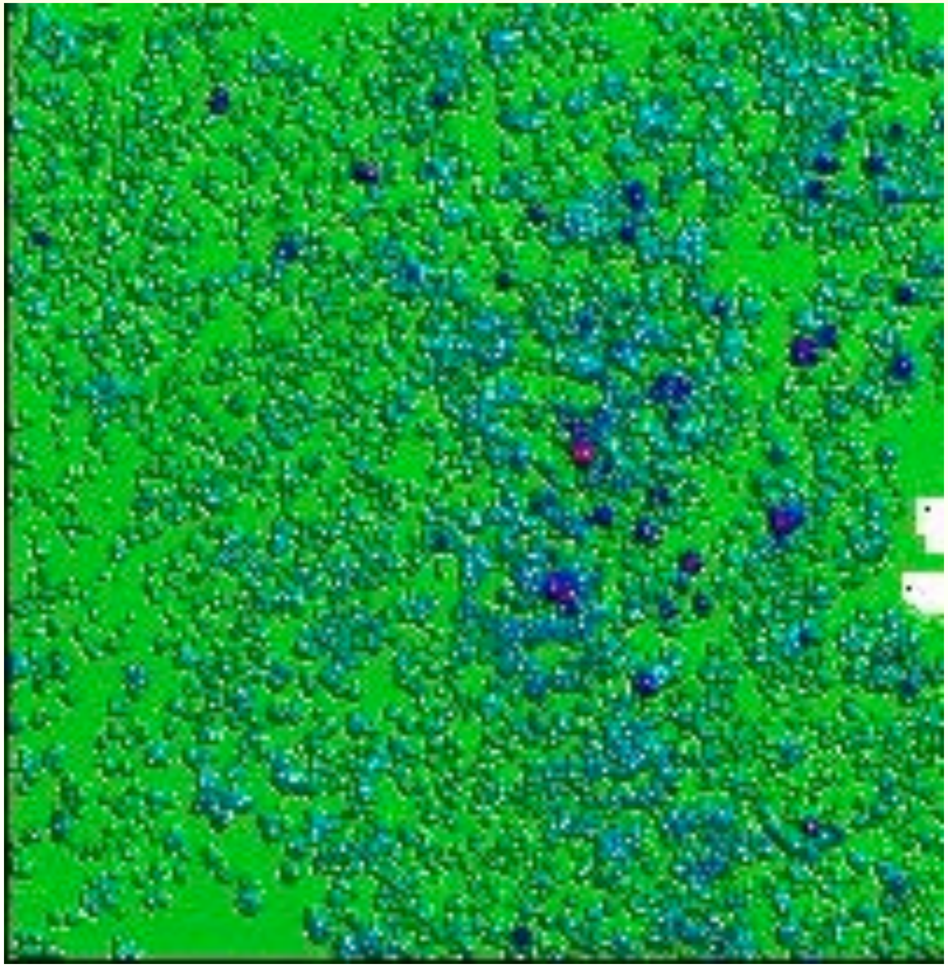


Woody elements (branches and stems)

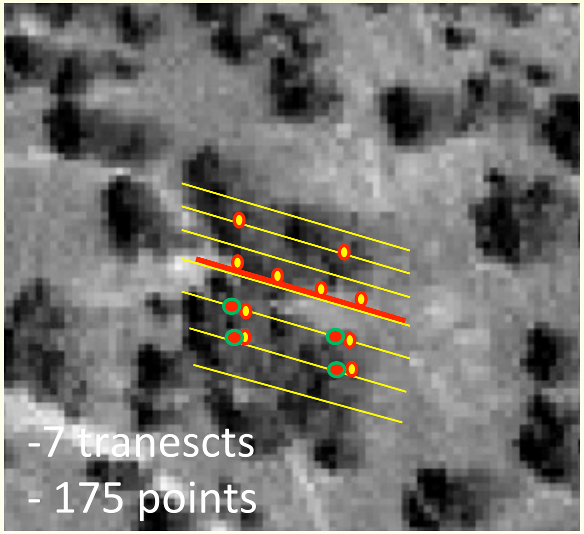
- The woody elements are explicitly considered in the 3D models.

Crown extraction by LiDAR

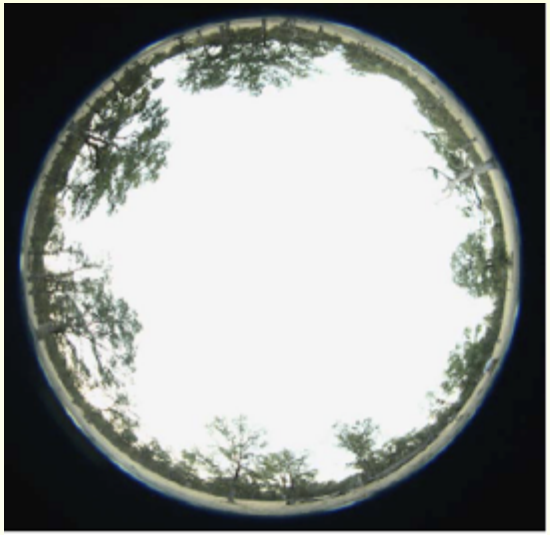
Crown extraction by automated extraction approach (Chen et al., 2007) (600x600m)



Estimation of leaf area density



The common way is to use hemispherical photo, but…



Ryu et al., 2010

Vertical photos are much better for LAI estimation

Spectral reflectances were measured by a field spectrometer

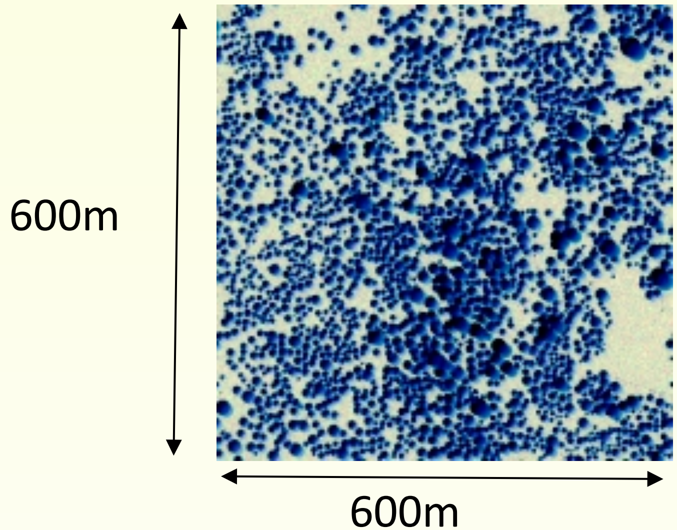
		PAR	NIR	TIR	450nm	550nm	650nm	780nm	900nm
Blue Oak leaf	ρ	0.085 (0.005)	0.282 (0.013)	0.02	0.077 (0.020)	0.123 (0.009)	0.075 (0.007)	0.513 (0.027)	0.510 (0.056)
	τ	0.028 (0.004)	0.251 (0.007)	0.00	0.008 (0.017)	0.072 (0.009)	0.022 (0.006)	0.441 (0.016)	0.459 (0.048)
	ε	-	-	0.98	-	-	-	-	-
Grass	ρ	0.090 (0.001)	0.306 (0.007)	0.02	0.067 (0.014)	0.157 (0.021)	0.072 (0.007)	0.534 (0.014)	0.499 (0.041)
	τ	0.065 (0.012)	0.270 (0.019)	0.00	0.018 (0.016)	0.157 (0.022)	0.046 (0.012)	0.455 (0.023)	0.455 (0.043)
	ε	-	-	0.98	-	-	-	-	-
Woody elements	ρ	0.171 (0.040)	0.343 (0.05)	0.02	0.127 (0.016)	0.170 (0.0087)	0.218 (0.013)	0.299 (0.021)	0.377 (0.026)
	ε	-	-	0.98	-	-	-	-	-
Ground*	ρ	0.105 (0.044)	0.253 (0.037)	0.98	0.055 (0.012)	0.102 (0.022)	0.156 (0.030)	0.225 (0.039)	0.276 (0.046)
	ε	-	-	0.98	-	-	-	-	-
Bare soil	ρ	-	-	-	0.033	0.065	0.108	0.170	0.220

Results

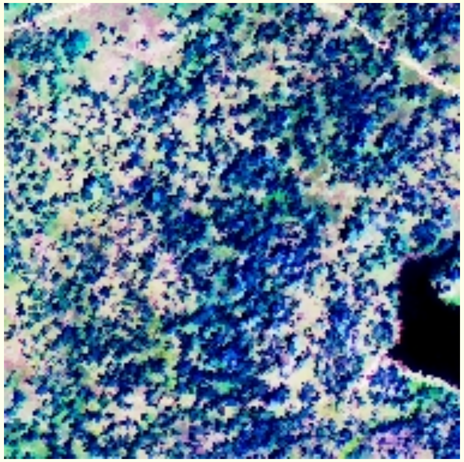
Canopy reflectance

May 12, 2006

Simulation

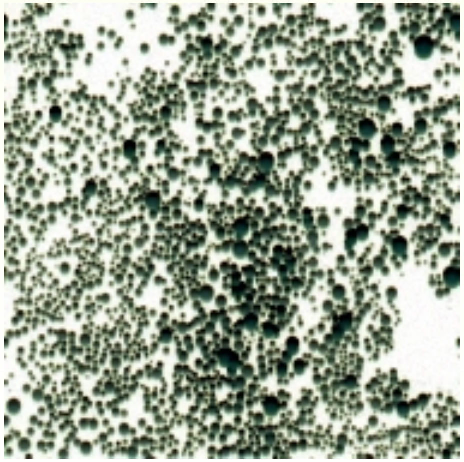


AVIRIS

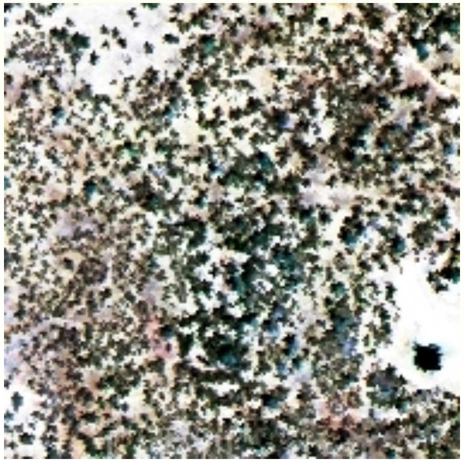


Aug 5, 2007

Simulation

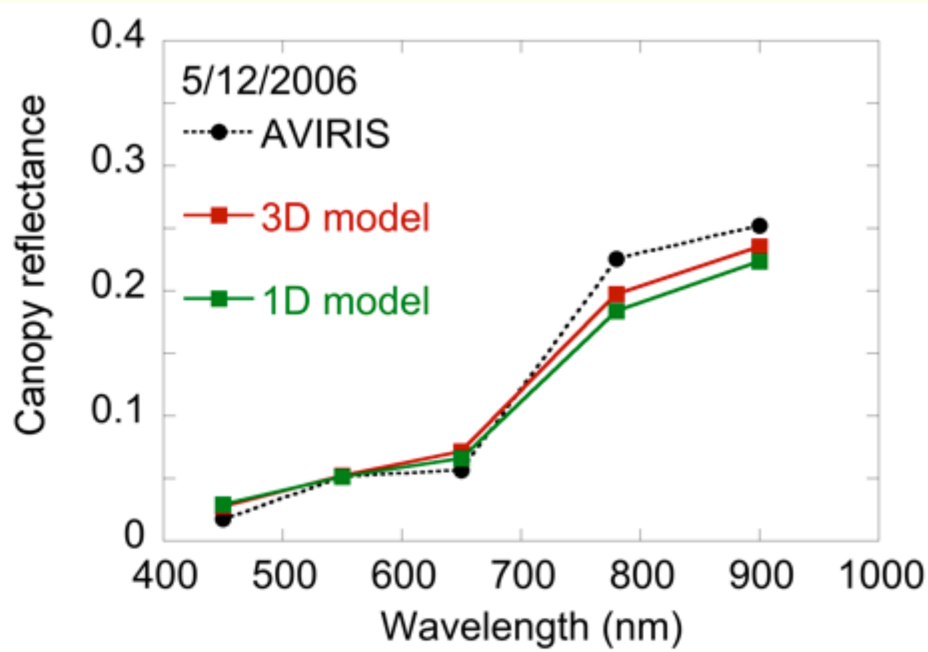


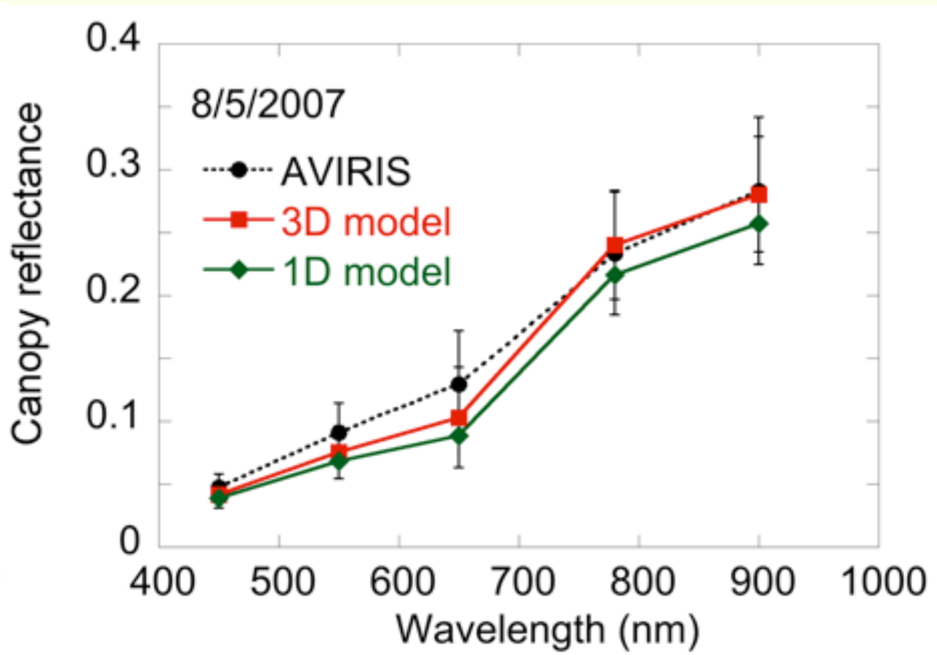
AVIRIS



Canopy spectral reflectance

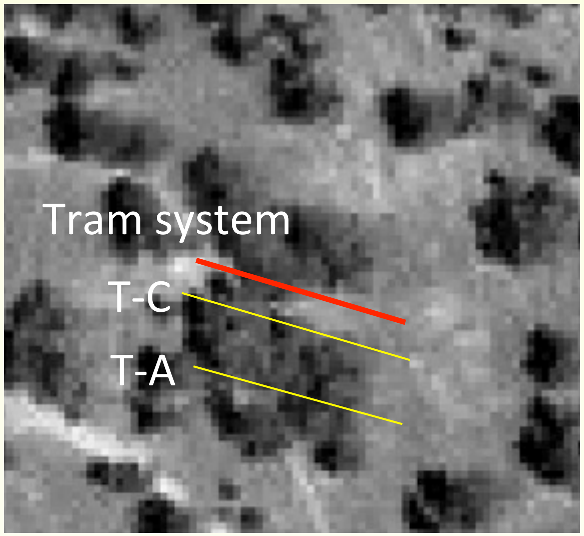
- Comparison with AVIRIS data

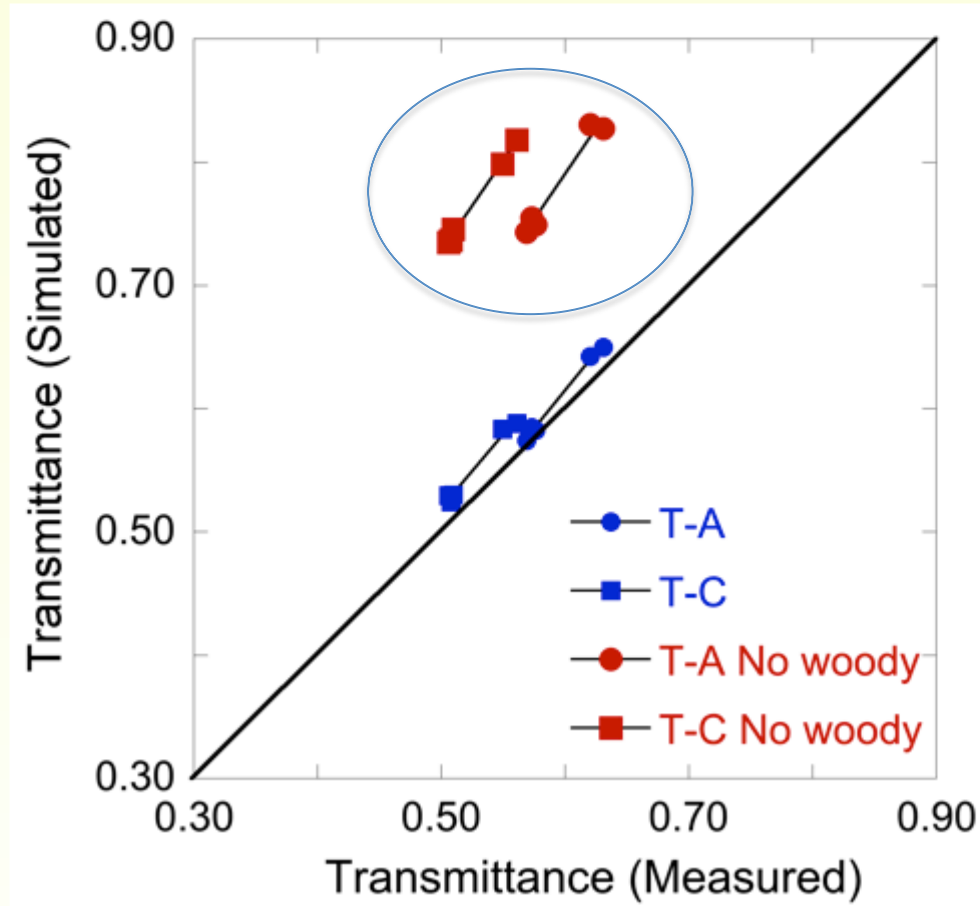




- The simulated results captured spectral patterns in reflectance
- The difference between 1D and 3D is very small

Spectral transmittance

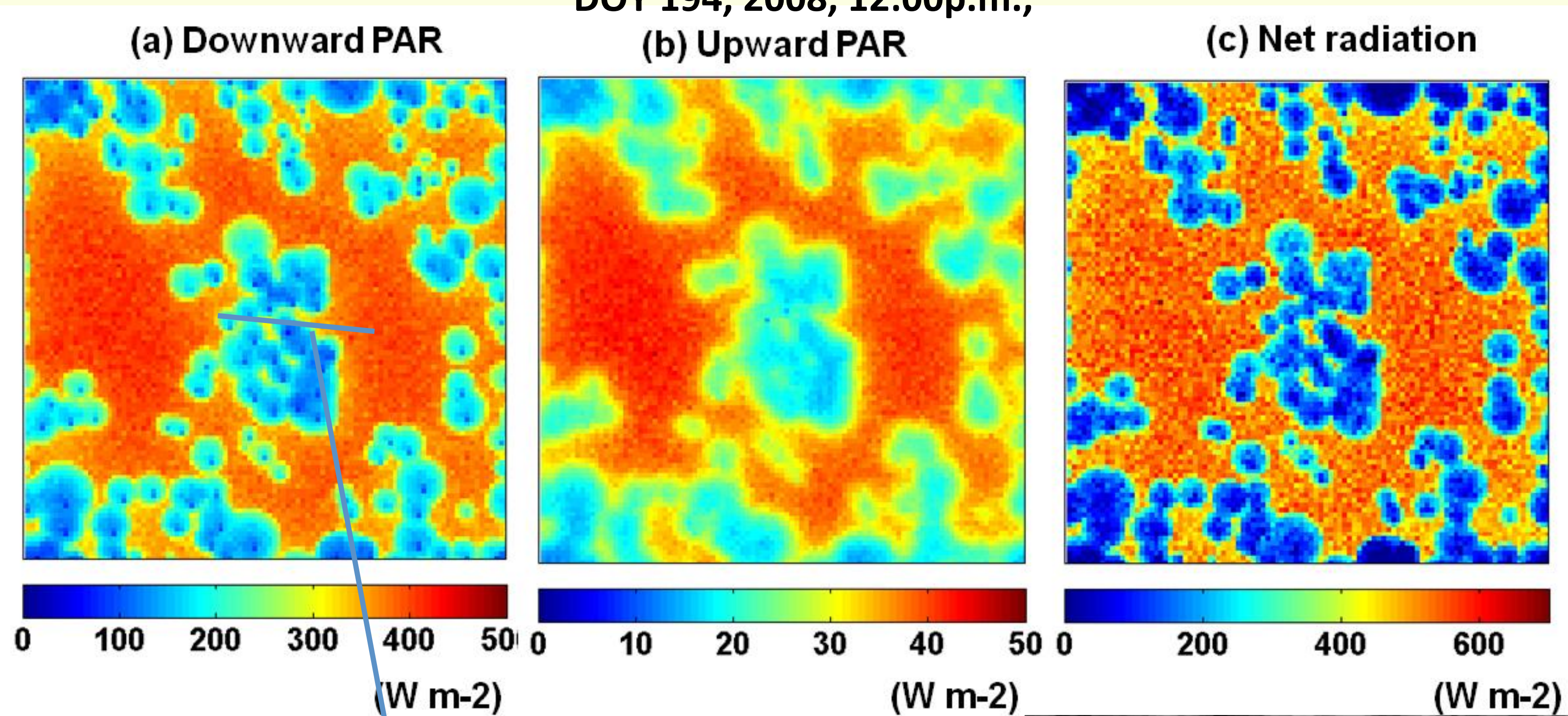




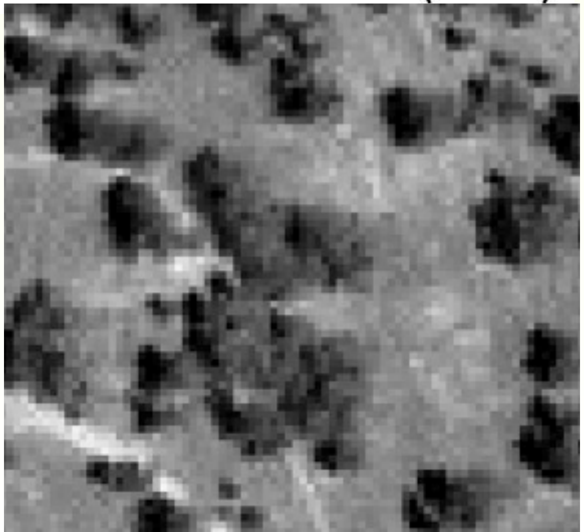
- Spectral transmittance for five spectral domain (450, 550, 640 ,780, 900 nm)
- 1D cases lower transmittance and higher slope than 1
- Without woody elements yield higher transmission

Transmittance and Rn at understory level

DOY 194, 2008, 12:00p.m.,

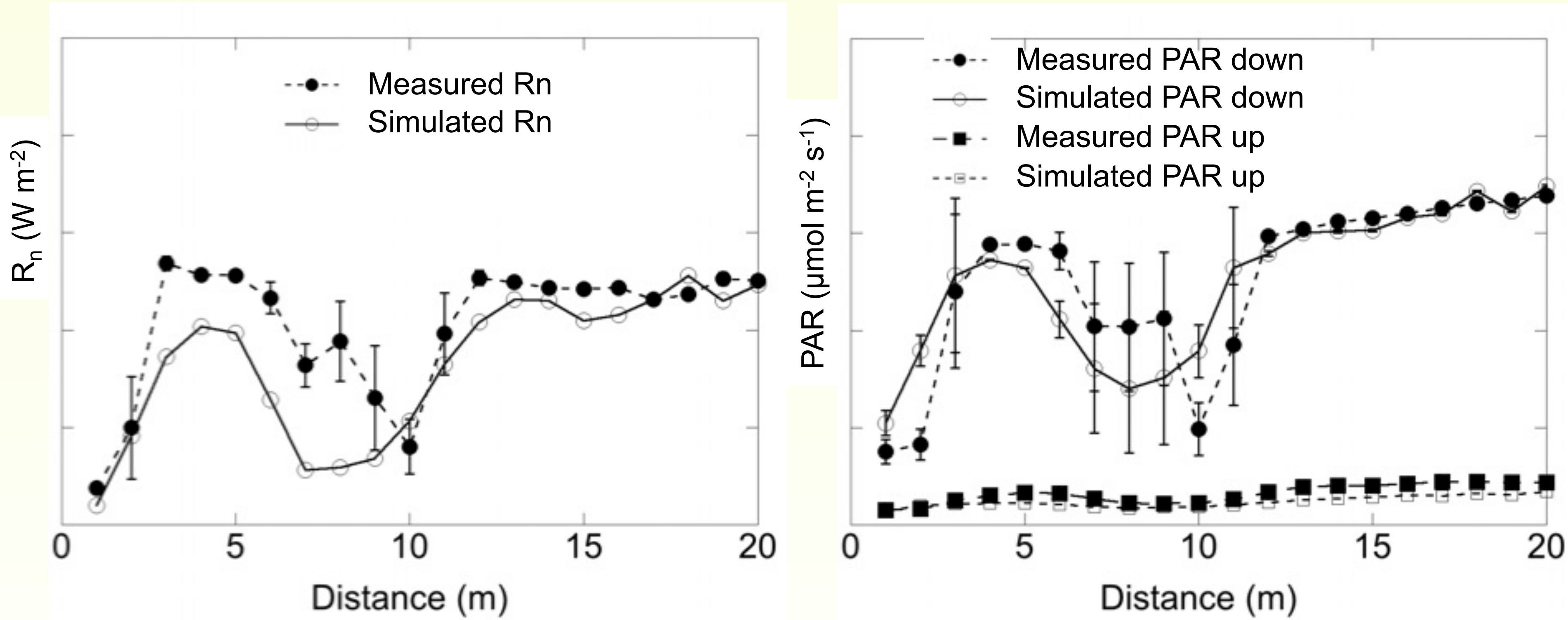


traversing radiometer system



Light environment at understory level

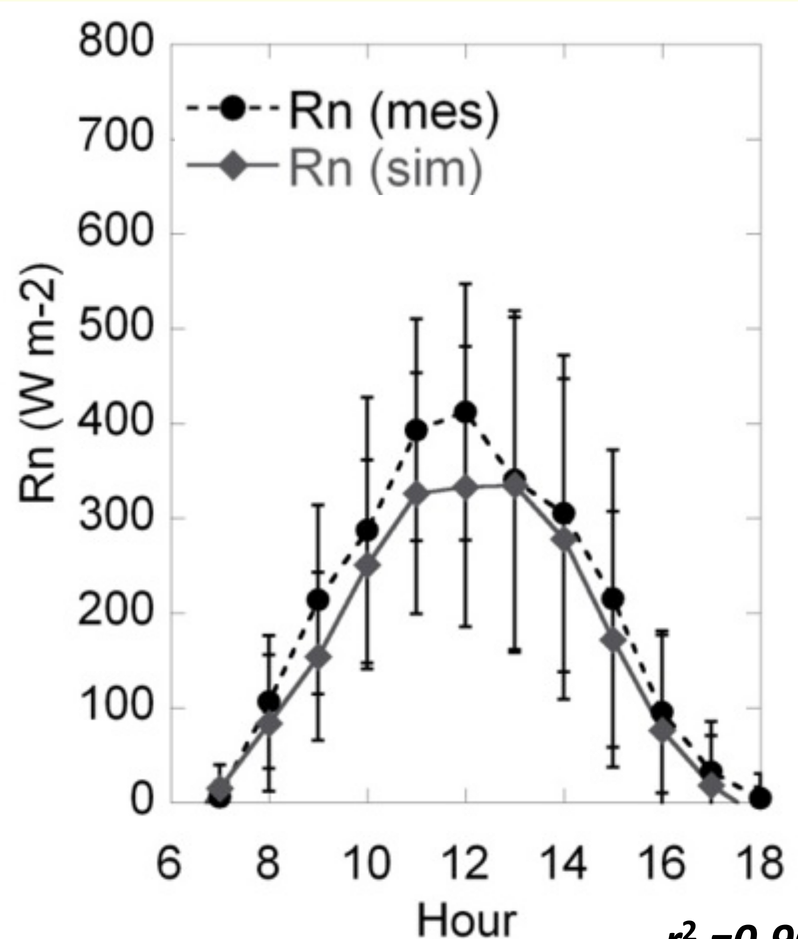
DOY 194 12:00

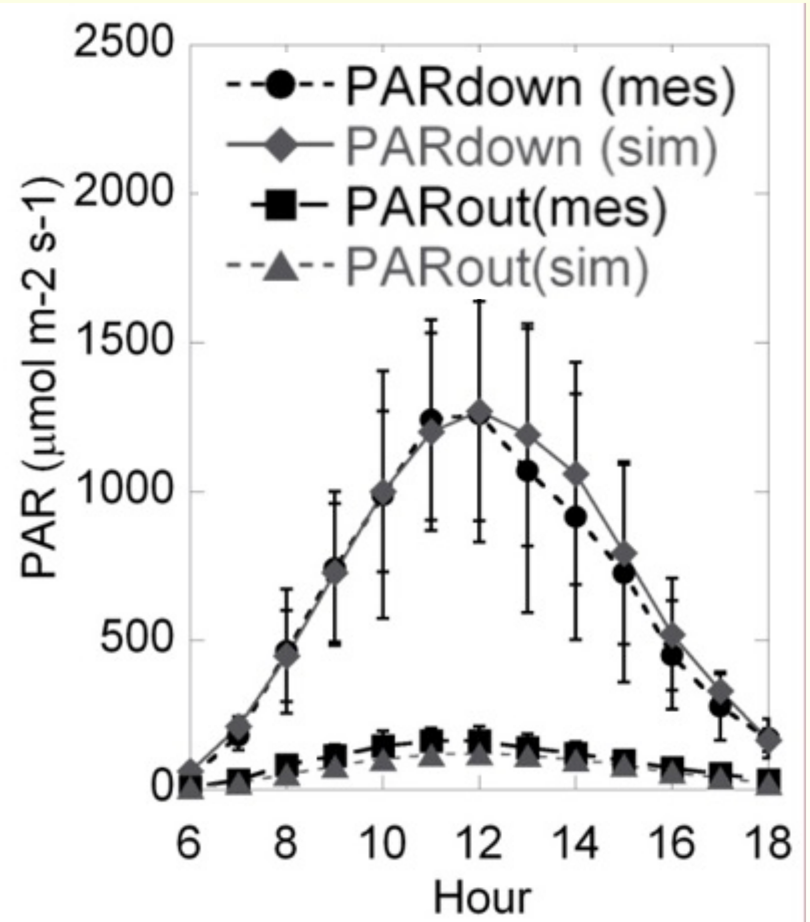


Although there are some mismatches in incident PAR and Rn along the rail track due to the mismatch of LiDAR derived crown position and size, 3D model captures general patterns.

Diurnal patterns (rail track averaged)

DOY 194



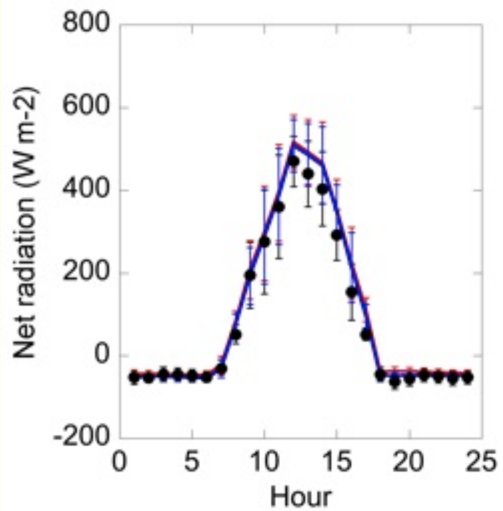


r^2 =0.90-0.97

Comparison with eddy covariance measurements (1D and 3D schemes)

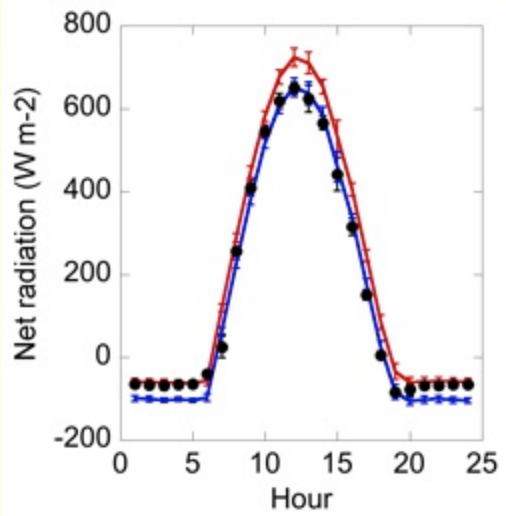
Diurnal patterns of net radiation

March (DOY 68-74)



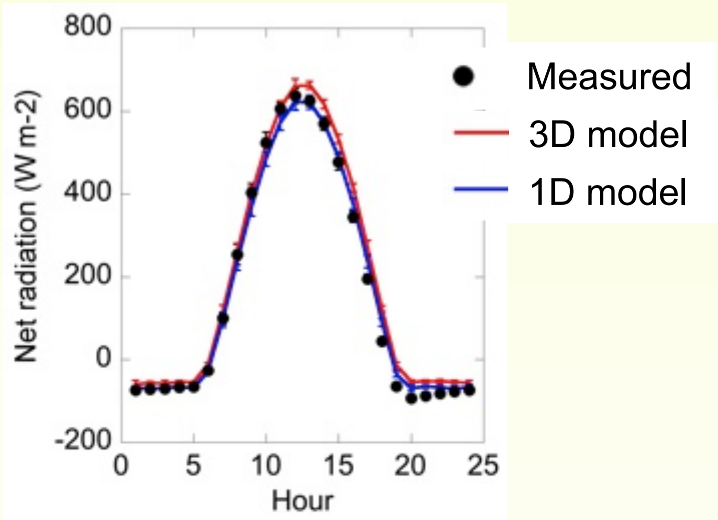
No tree leaves
Green understory

May (DOY115-121)



Green tree leaves
Green understory

July (DOY 204-210)

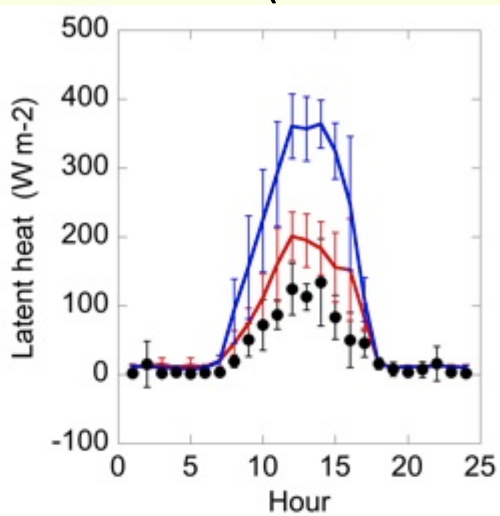


Green tree leaves
Understory: dead leaves

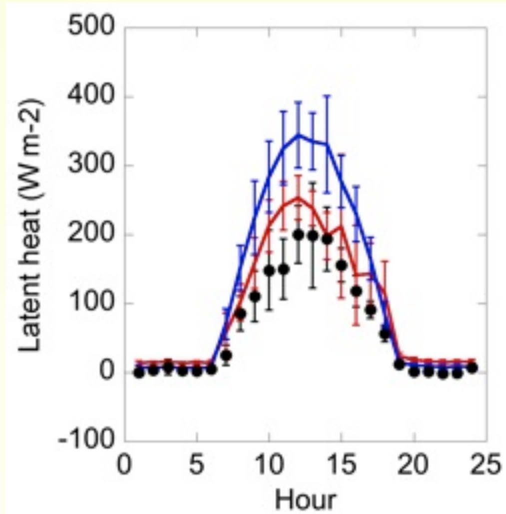
Both 1D and 3D look good over the three difference phenology stages
Net radiation of the 3D scheme has a little positive bias for May

Diurnal patterns of Evapotranspiration

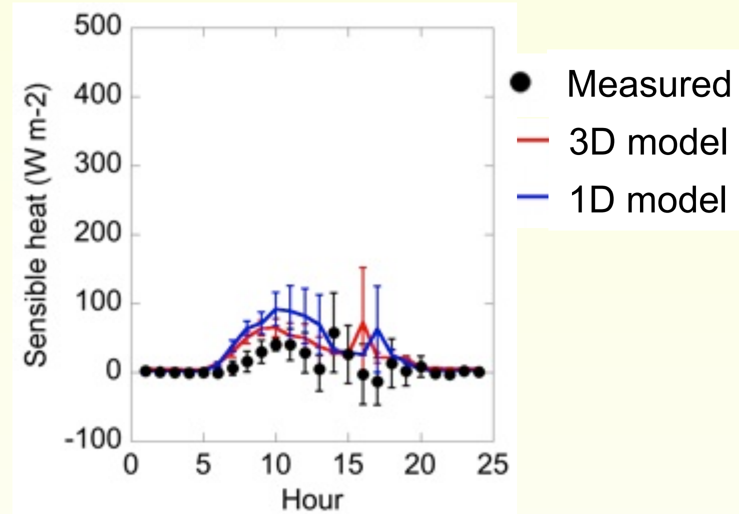
March (DOY 68-74)



May (DOY115-121)



July (DOY 204-210)



No tree leaves
Green understory

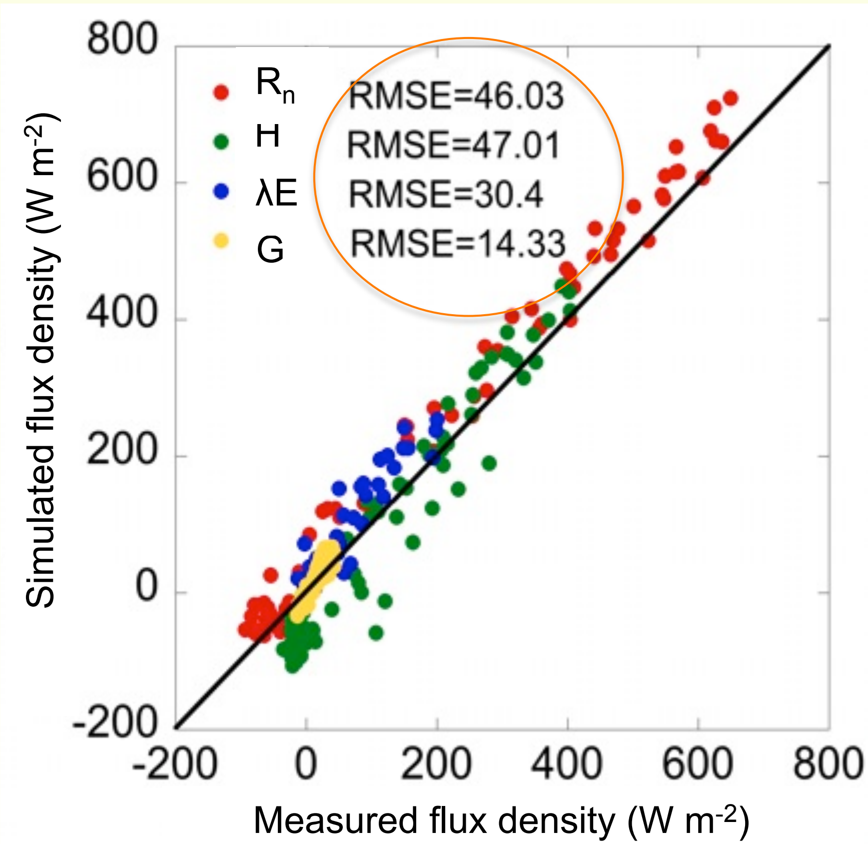
Green tree leaves
Green understory

Green tree leaves
Understory: dead leaves

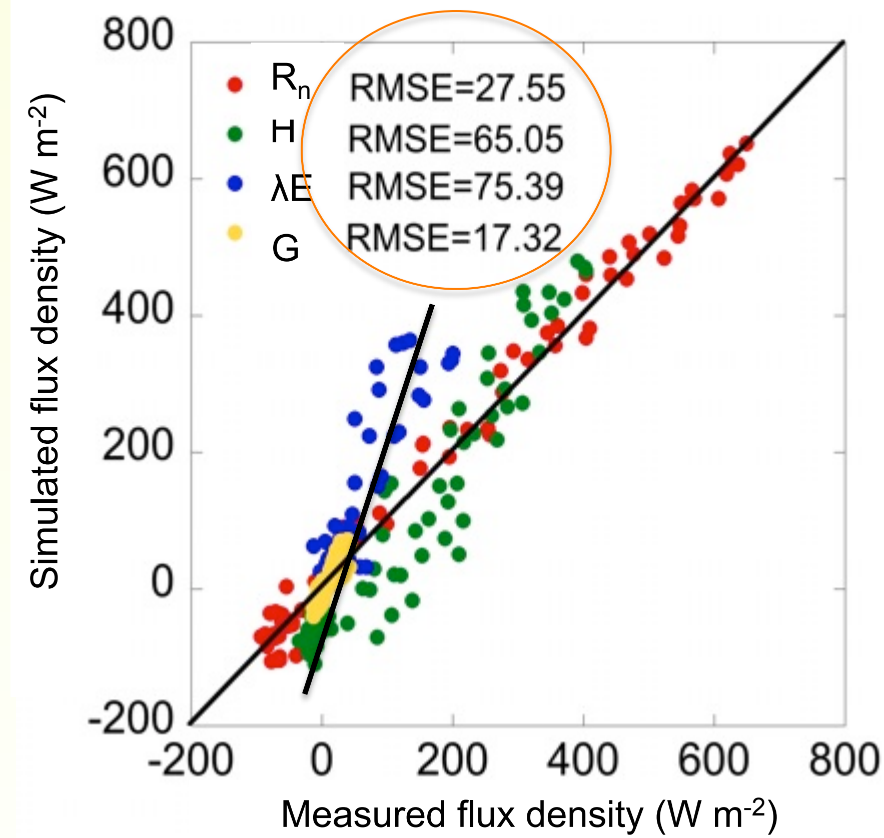
ETs simulated by the 3D schemes perform better than that of 1D

Comparison with eddy covariance measurements

3D scheme



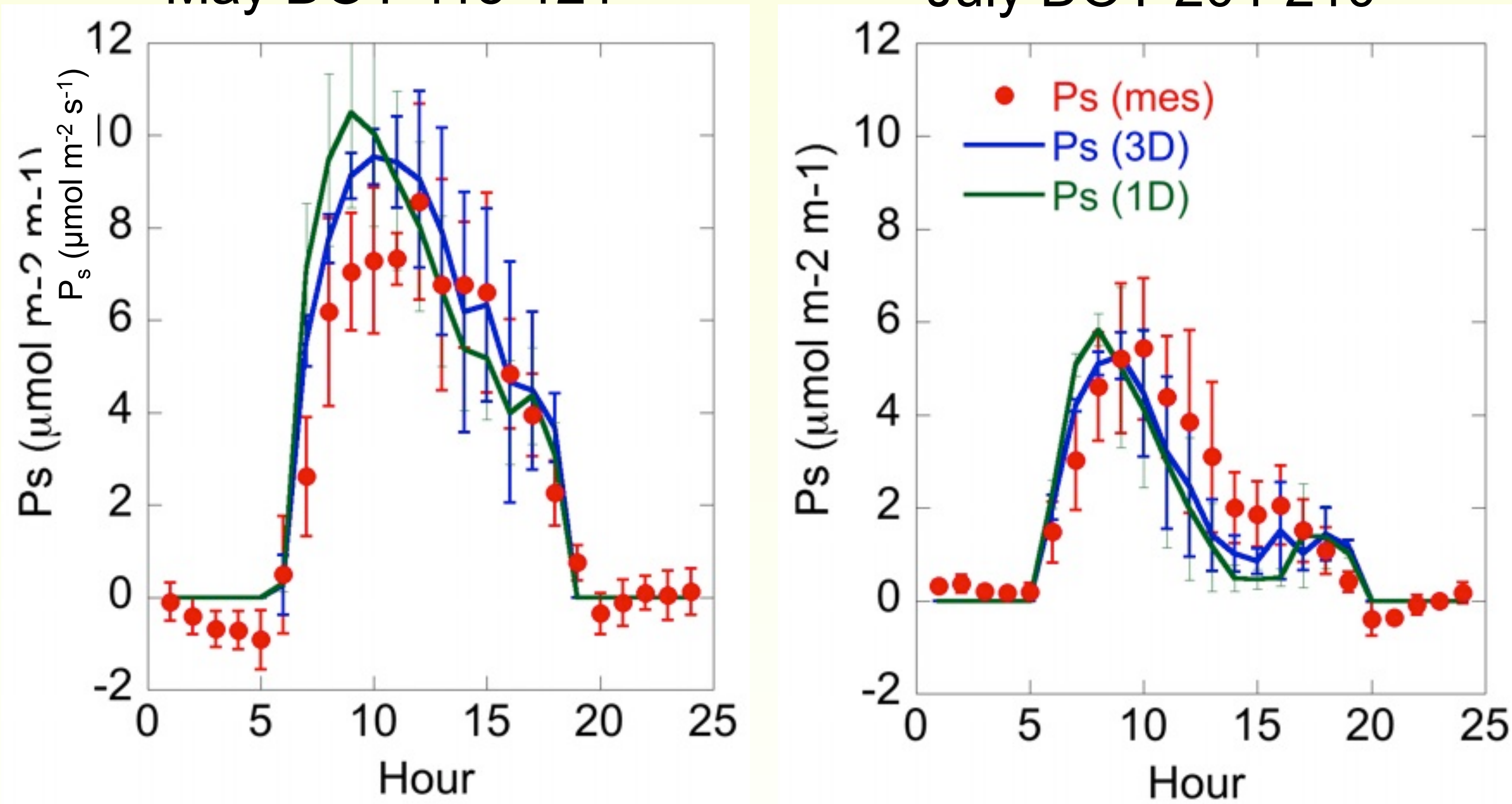
1D scheme



Flux densities in the 3D schemes perform better than that of 1D (except for Rn)

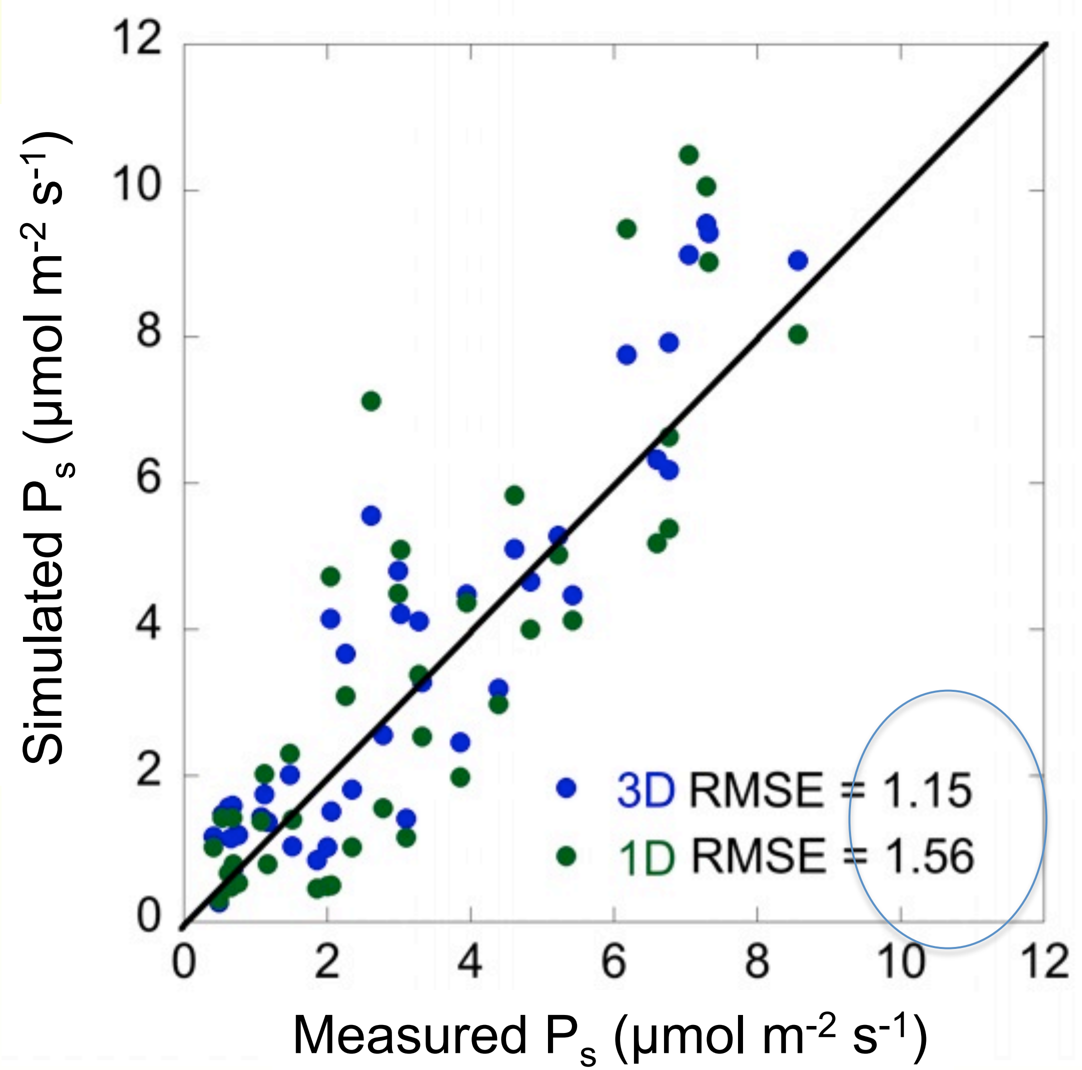
Tree photosynthesis

May DOY 115-121 / July DOY 204-210



- Ps in 1D case tends to be higher in the morning.
- Afternoon, there are small differences in Ps
- Importance of the light environment depends on the water availability

Comparison with eddy covariance measurements



Summary

- The 3D model mostly captured the spatial and temporal patterns of radiation environments as well as energy and carbon fluxes
- The 3D scheme generally performed better than the 1D scheme.
  - The 3D approach is more important in wet mild (light-limited) periods than dry (water-limited) periods. The significant ET and P_s differences were found in wet mild weather periods because of high radiation sensitivity to ET and P_s.

- The 3D model has the potential to use as a tool for analyzing the spatial and temporal variability of radiation and energy fluxes

Thank you for your attention

Acknowledgement

- The Postdoctoral Fellowship for Research Abroad of Japan Society for the Promotion of Science (JSPS).
- The Office of Science (BER) of the U.S. Department of Energy (DE-FG02-03ER63638 and DE-SC0005130).