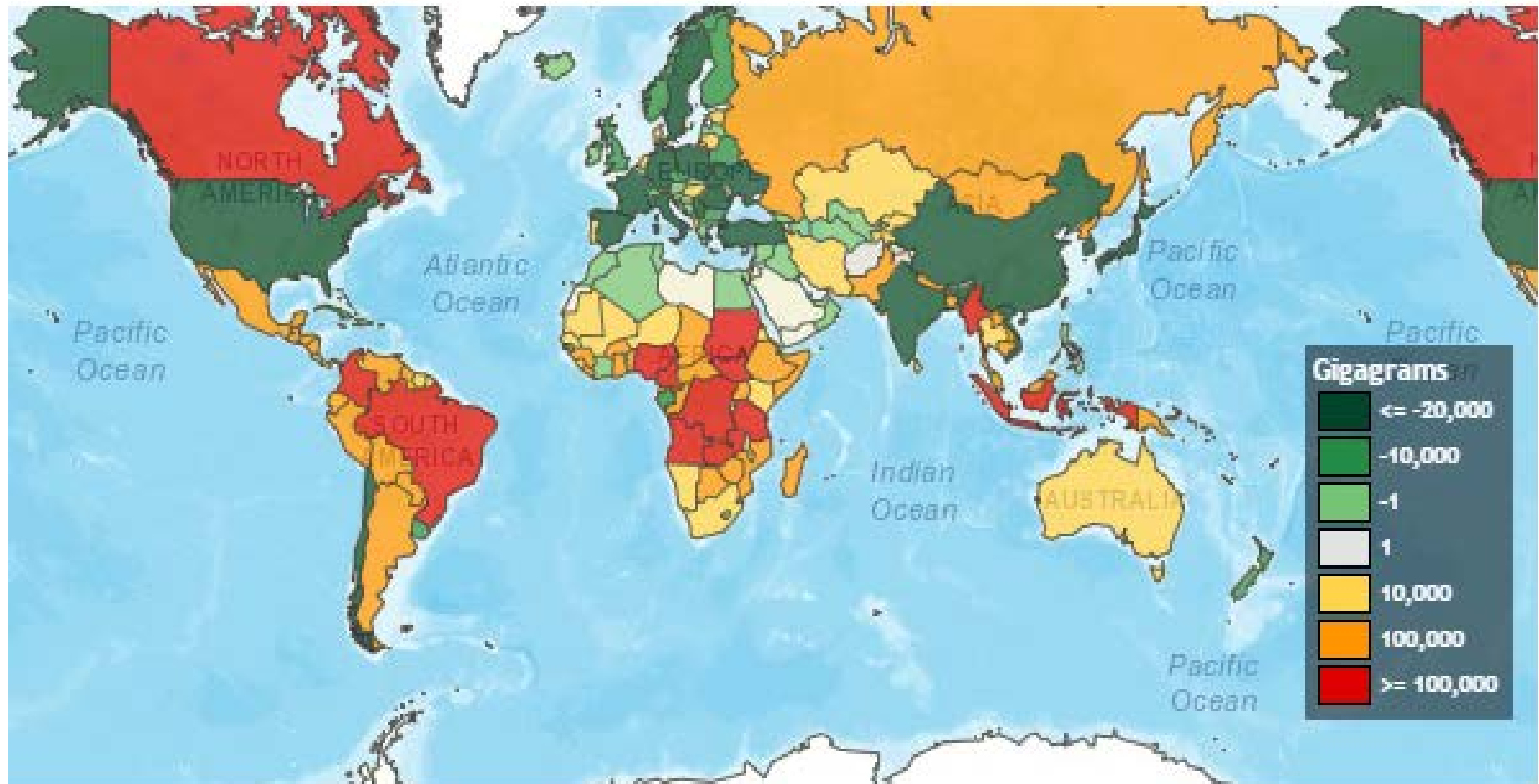# Modeling biophysical and biogeochemical processes of agricultural land use system: CLM-Palm and beyond
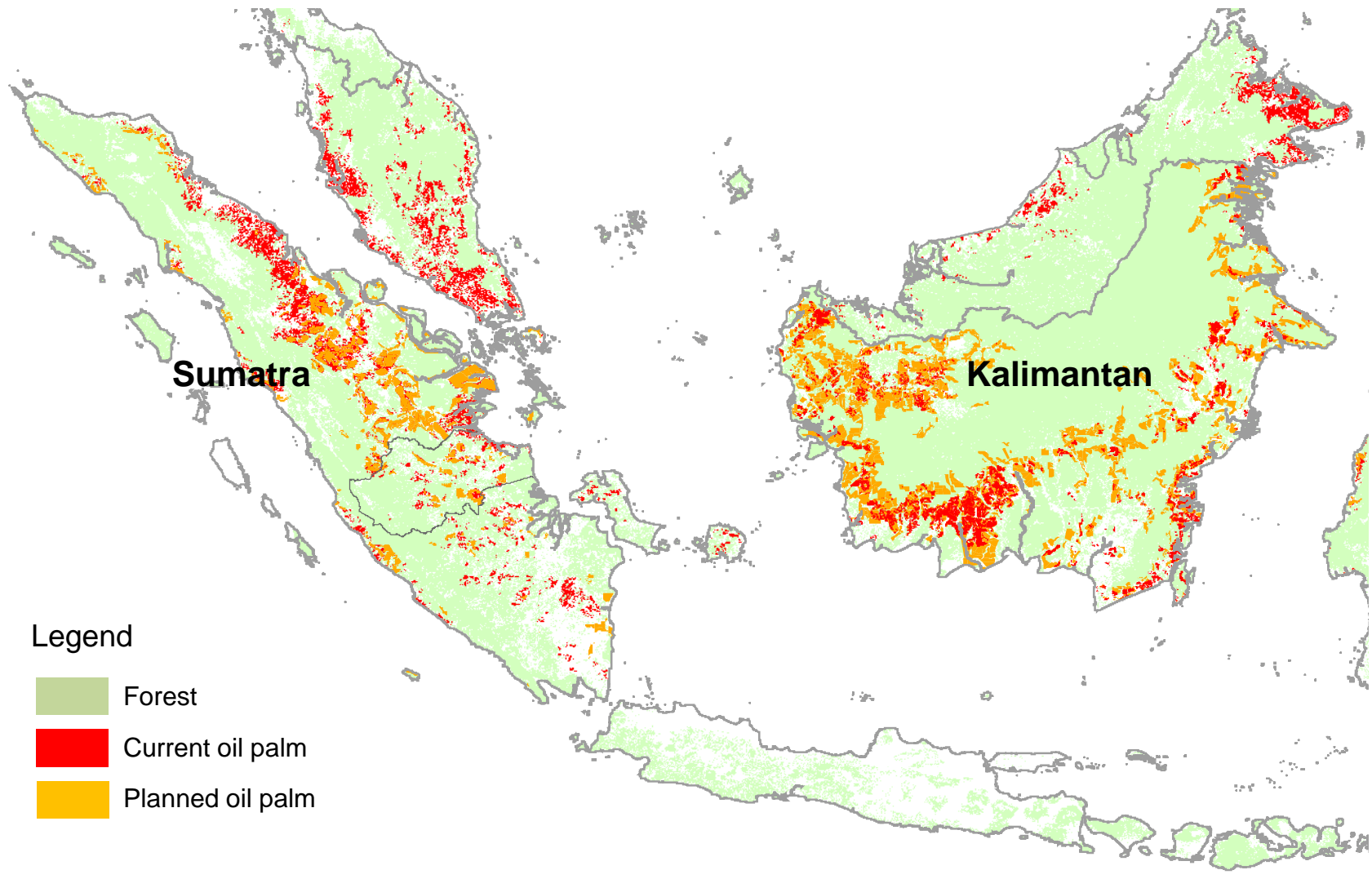
Yuanchao Fan
Uni Research Climate
Bjerknes Centre for Climate Research, Bergen, Norway
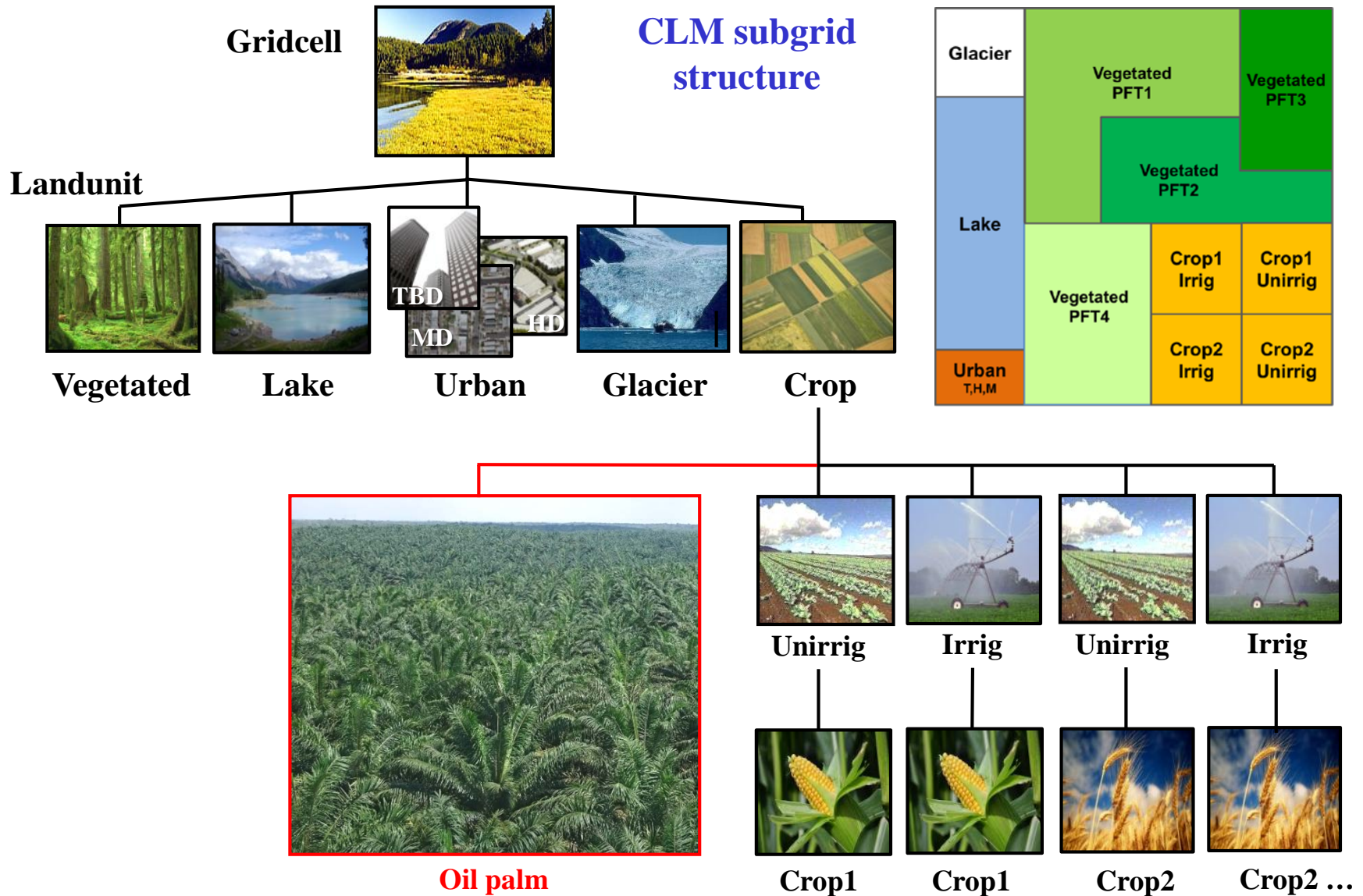
Carbon emissions from land use

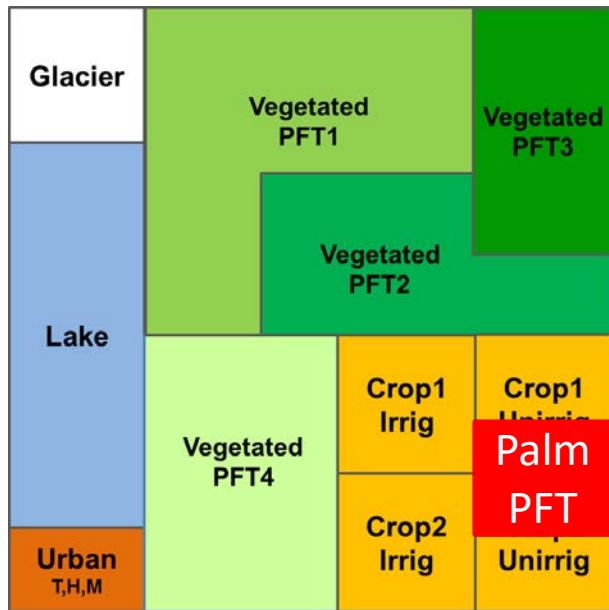Net emissions (+) /removals (–) of GHG from land use (CO2eq, average 1990 – 2014).

From rainforests to oil palm plantations
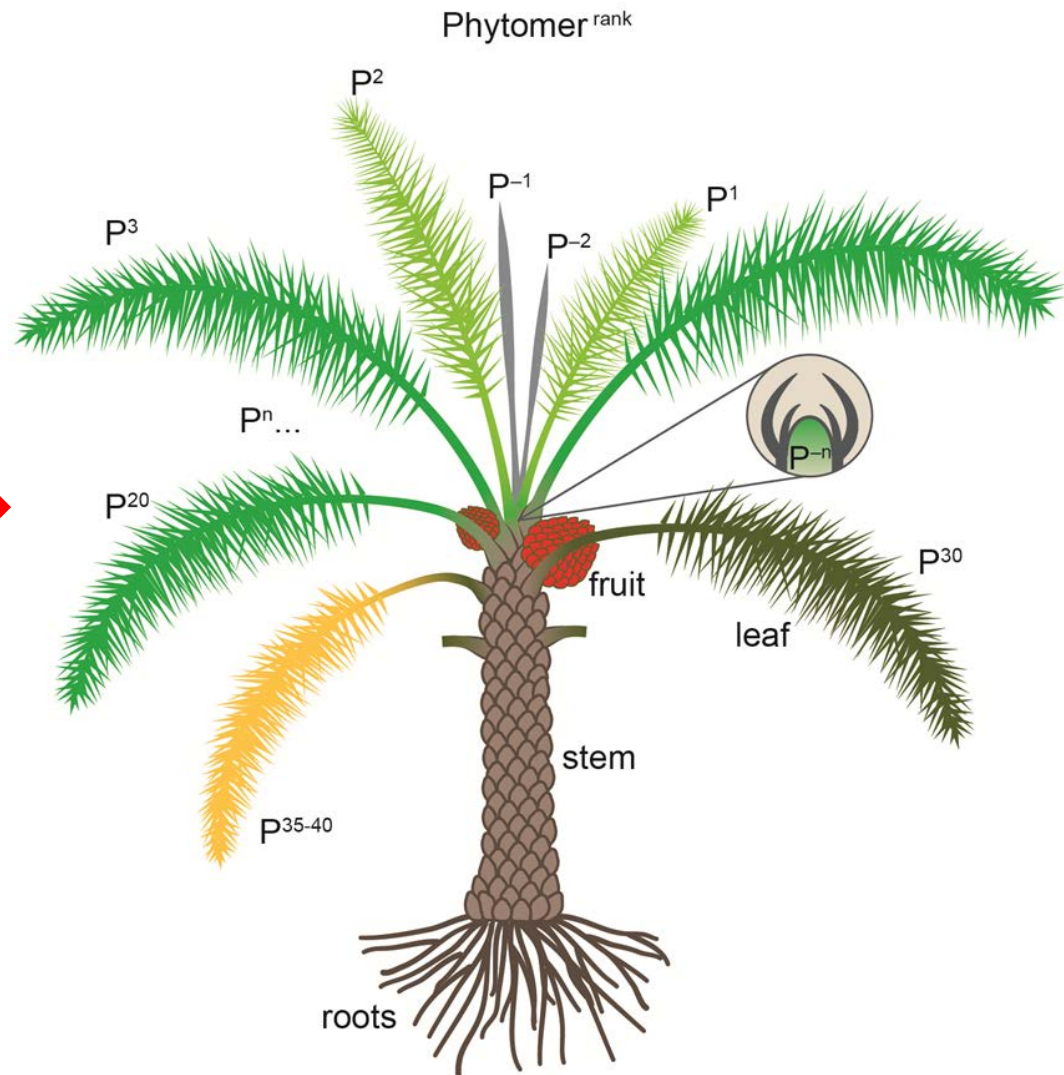

Sumatra

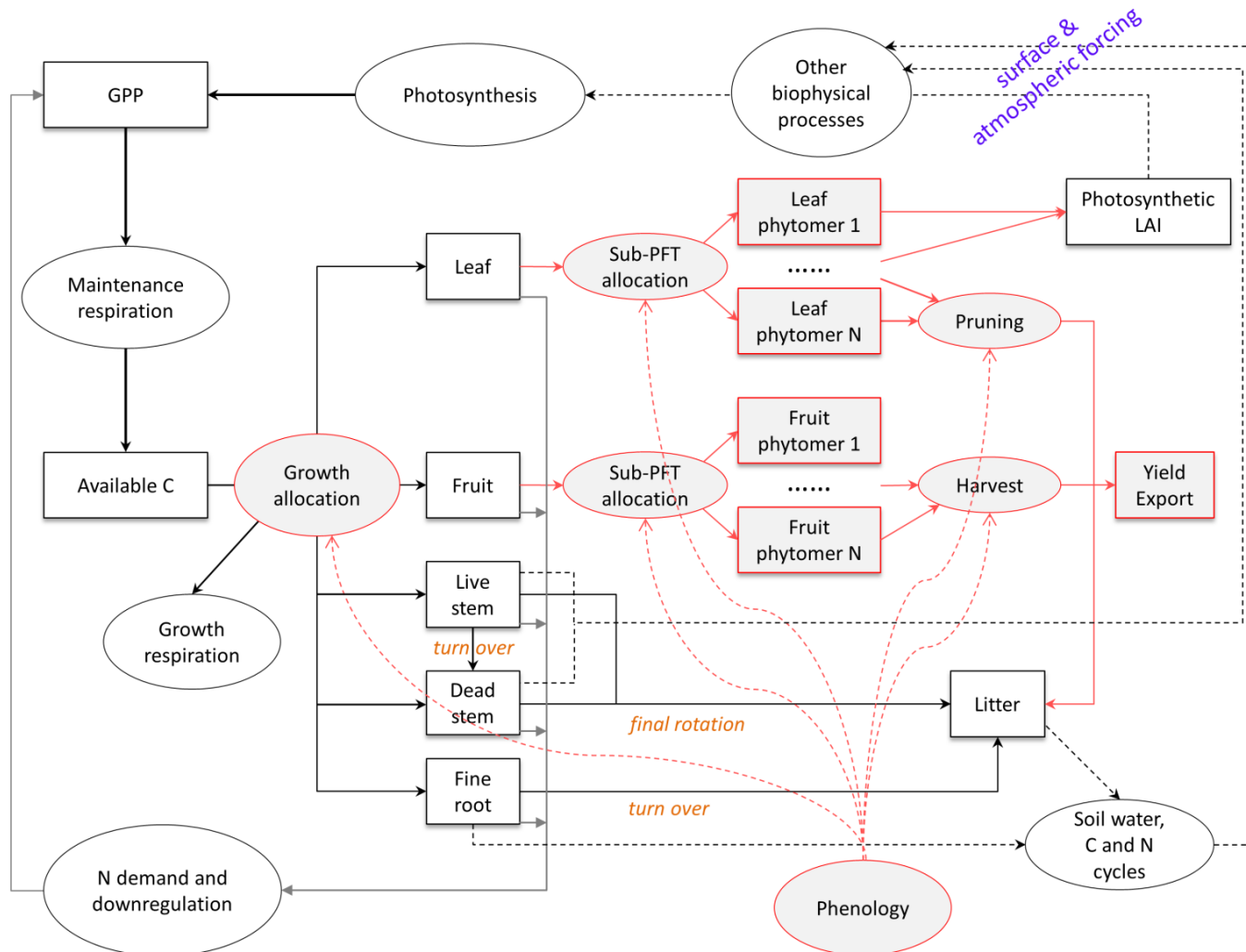**Kalimantan**

Legend

Forest

Current oil palm

Planned oil palm

Modeling oil palm monoculture and its associated impacts on land-atmosphere carbon, water and energy fluxes in Indonesia (Fan 2016 Dissertation)

Theoretical framework

Gridcell

CLM subgrid structure

Landunit

Vegetated   **Lake**   **Urban**   **Glacier**   **Crop**

TBD   MD   HD

Oil palm

Unirrig   **Irrig**   **Unirrig**   **Irrig**

Crop1   **Crop1**   **Crop2**   **Crop2 …**

Source: Lawrence et al., 2011; Oleson, et al., 2013; NCAR; Boulder, CO, USA

A new Plant Functional Type (PFT)

Grid cell

Glacier
Lake
Urban T,H,M
Vegetated PFT1
Vegetated PFT2
Vegetated PFT3
Vegetated PFT4
Crop1 Irrig
Crop1 Unirrig
Crop2 Irrig
Unirrig
Palm PFT

Phytomer^{rank}
P^2
P^{-1}
P^1
P^3
P^{-2}
P^n...
P^{-n}
P^{20}
fruit
P^{30}
leaf
stem
P^{35-40}
roots

New structure and processes in CLM-Palm

Fan et al. 2015, Geoscientific Model Development, 8, 3785-3800

Sub-PFT (phytomer) phenology

Expansion of phytomer at rank 1

Leaf initiation

Leaf expansion

Leaf maturity

Fruit-filling

Fruit harvest

Leaf senescence

Leaf pruning

......

Rank 3

Rank 2

Rank 1

Rank -1

Rank -2

Rank -3

......

Phytomers initiate successively

H_p^{init}

$H_p^{L.exp}$

$H_p^{L.mat}$

$H_p^{F.fill}$

$H_p^{F.mat}$

$H_p^{L.sen}$

A phyllochron

Growing degree days
(base 15°C)
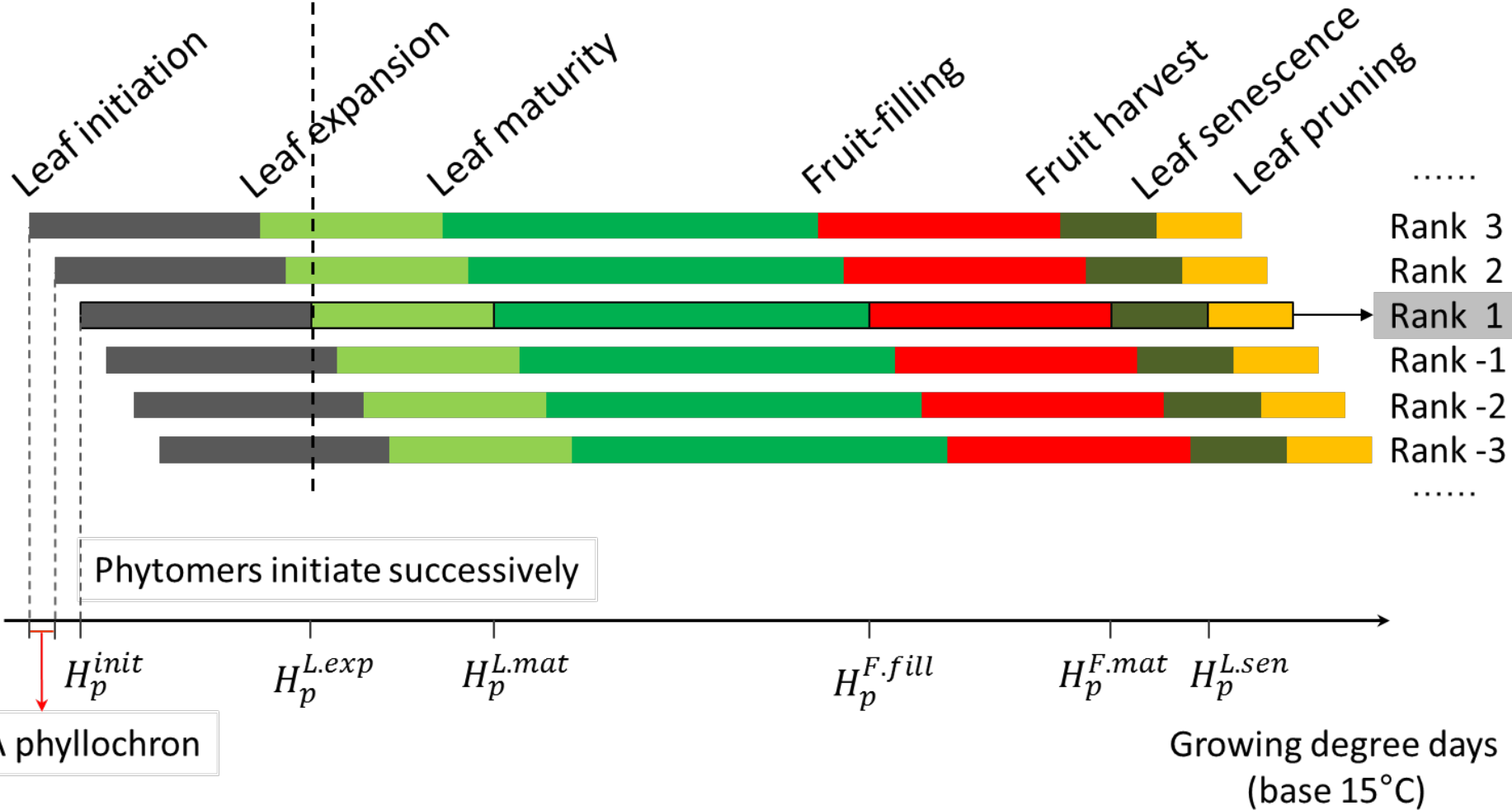
Compare with field data

Energy

DIFFUSE SOLAR DIRECT SOLAR

REFLECTED SOLAR

ABSORBED SOLAR

DOWNWELLING LONGWAVE
EMITTED LONGWAVE

AEROSOL DEPOSITION

SENSIBLE HEAT FLUX
LATENT HEAT FLUX

MOMENTUM FLUX
WIND SPEED

DUST
SCF

GROUND HEAT FLUX

SURFACE WATER

SOIL (SAND, CLAY, ORGANIC)

Hydrology

PRECIPITATION

CANOPY EVAPORATION
TRANSPIRATION

INTERCEPTION

THROUGHFALL

INFILTRATION
GROUND EVAPORATION
SURFACE RUNOFF

SUBLIMATION
SNOW MELT

SOIL

SATURATED FRACTION

AQUIFER RECHARGE
WATER TABLE

SUB-SURFACE RUNOFF

UNCONFINED AQUIFER

Biogeochemistry

CLM-Palm

PHOTOSYNTHESIS

CO_2

PHENOLOGY

AUTOTROPHIC RESPIRATION

N DEPOSITION
N FIXATION
CH_4
N_2O
BVOCS

FIRE
LITTERFALL

C:N−   C:N+
Dynamic N

HETEROTROPHIC RESPIRATION

ROOT LITTER

SOIL C/N
N MINERALIZATION

N⁺

N UPTAKE   DENITRIFICATION
N LEACHING

microbes

Glacie

Wetland

Ri
Ro

Flooding

River discharge

Urban

Wood harvest

Land Use Change

Pruning

Senescence   Leaf initiation

Fruit harvest

Leaf expansion

Fruit filling

Leaf maturity

Canopy hydrology:
Caveat of forcing frequency

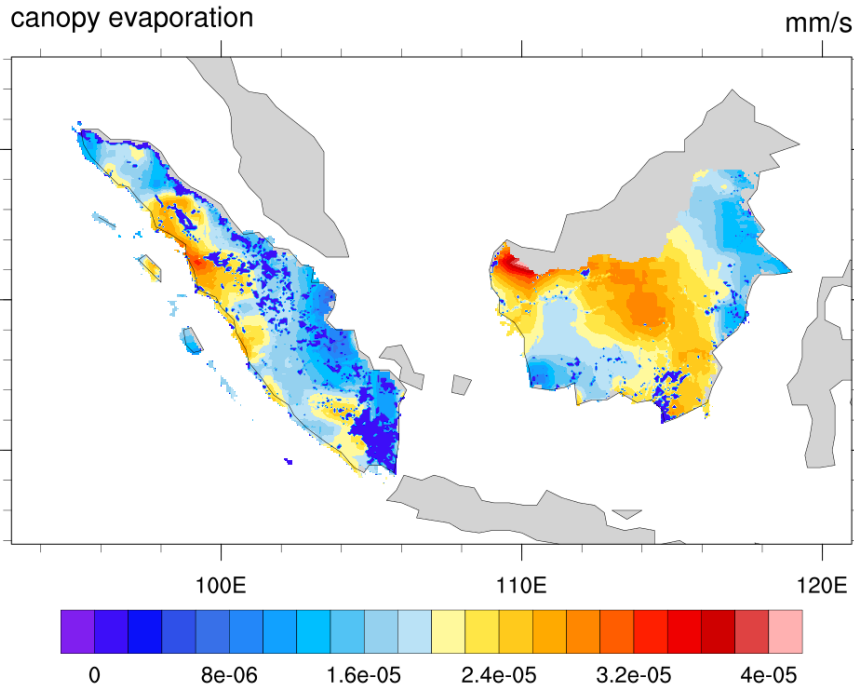(a) Rain distribution
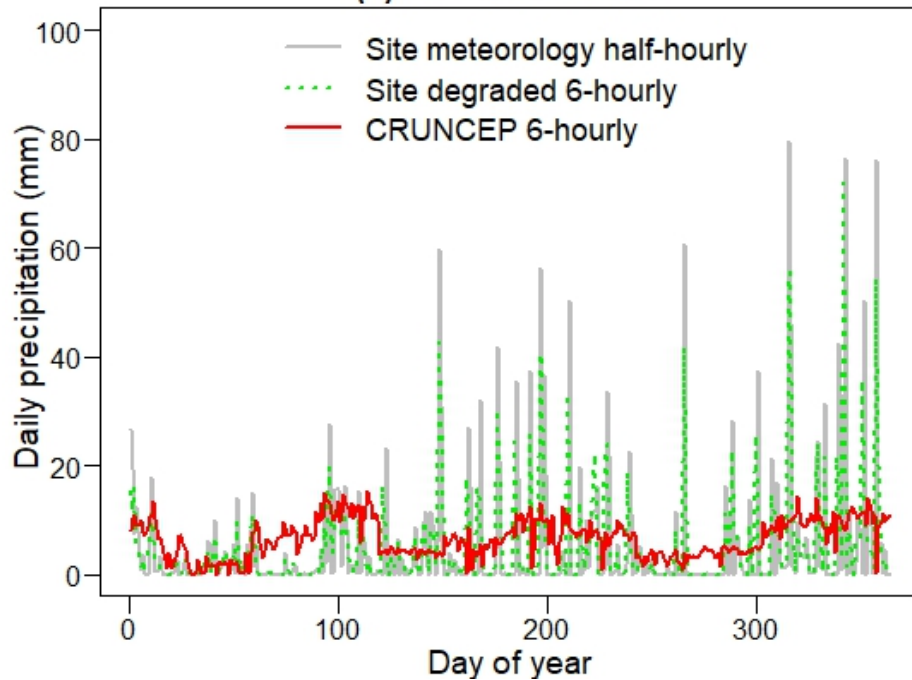
(b) Rainfall amount and frequency
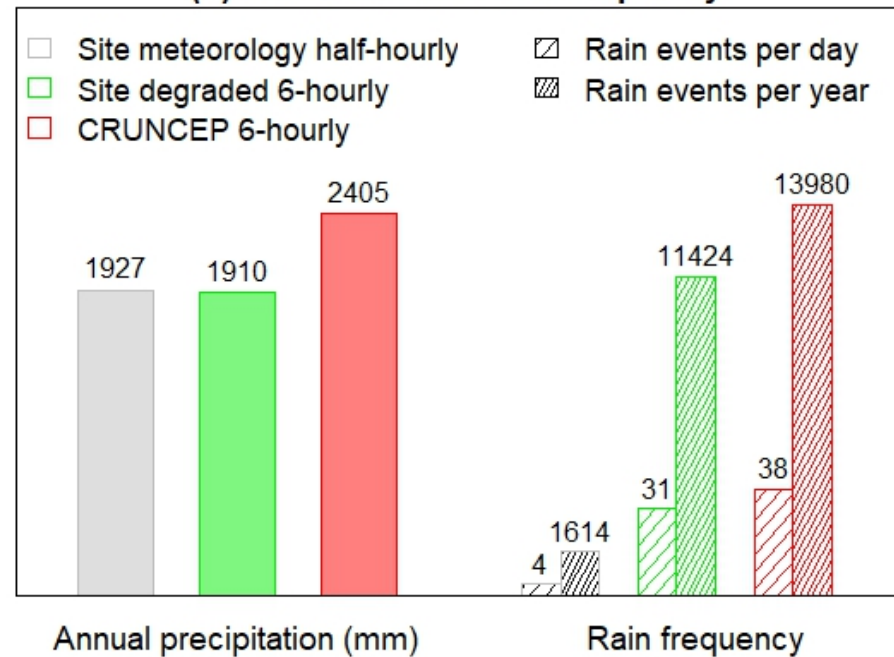
Degraded forcing frequency influences canopy evaporation and transpiration
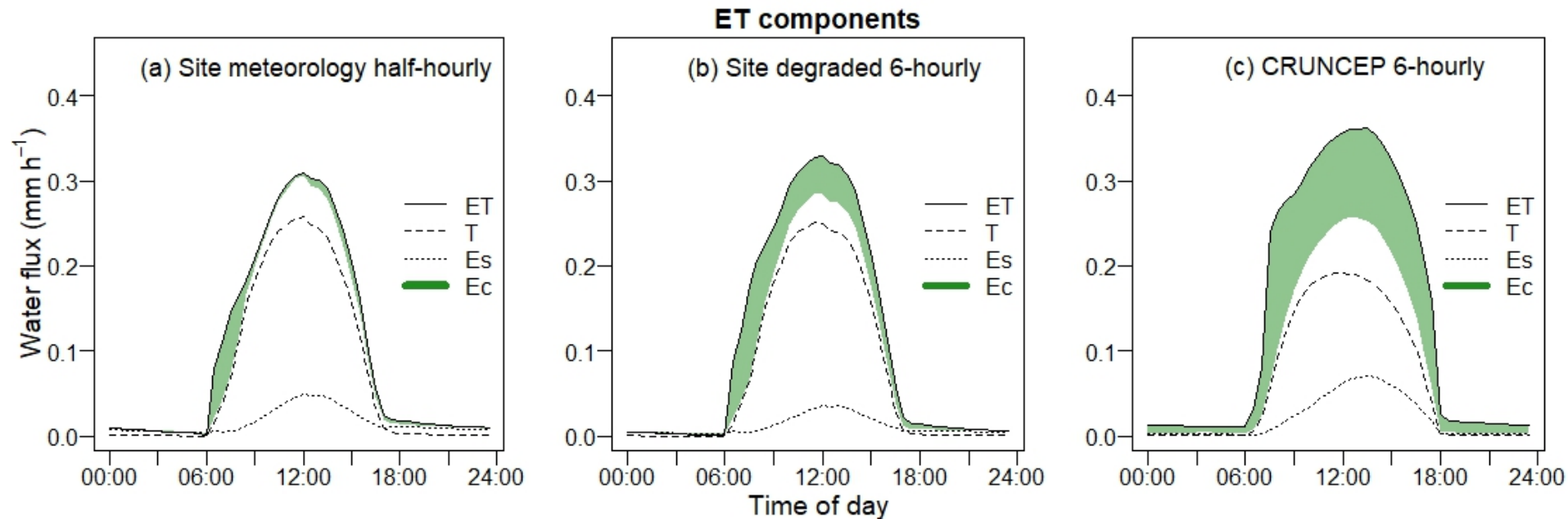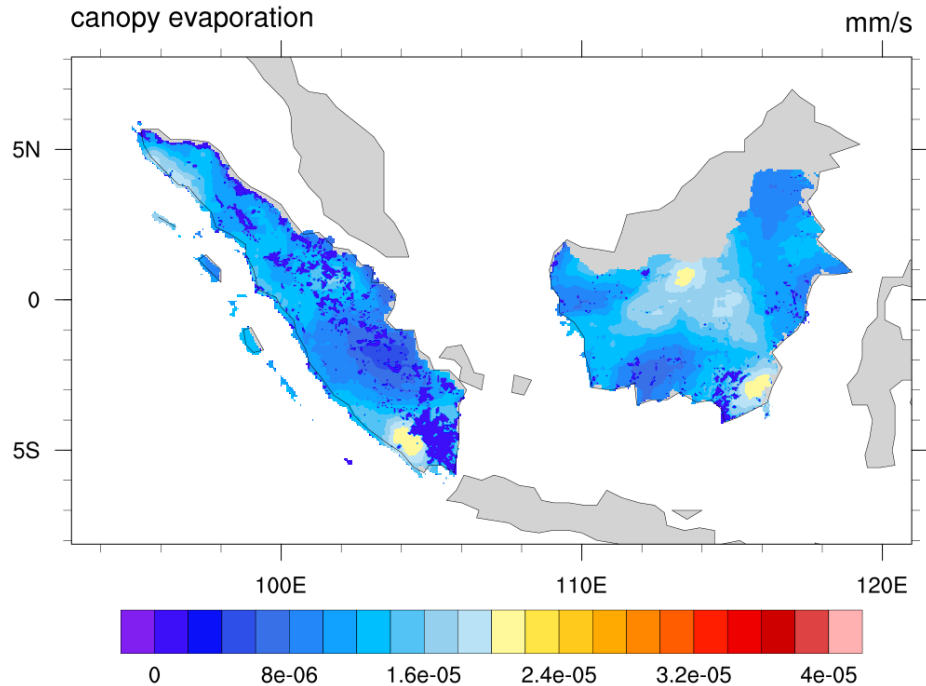

evapotranspiration (ET), transpiration (T), soil evaporation (E_S) and canopy evaporation (E_C) for tropical forest

Canopy evaporation over Indonesia forests and oil palms
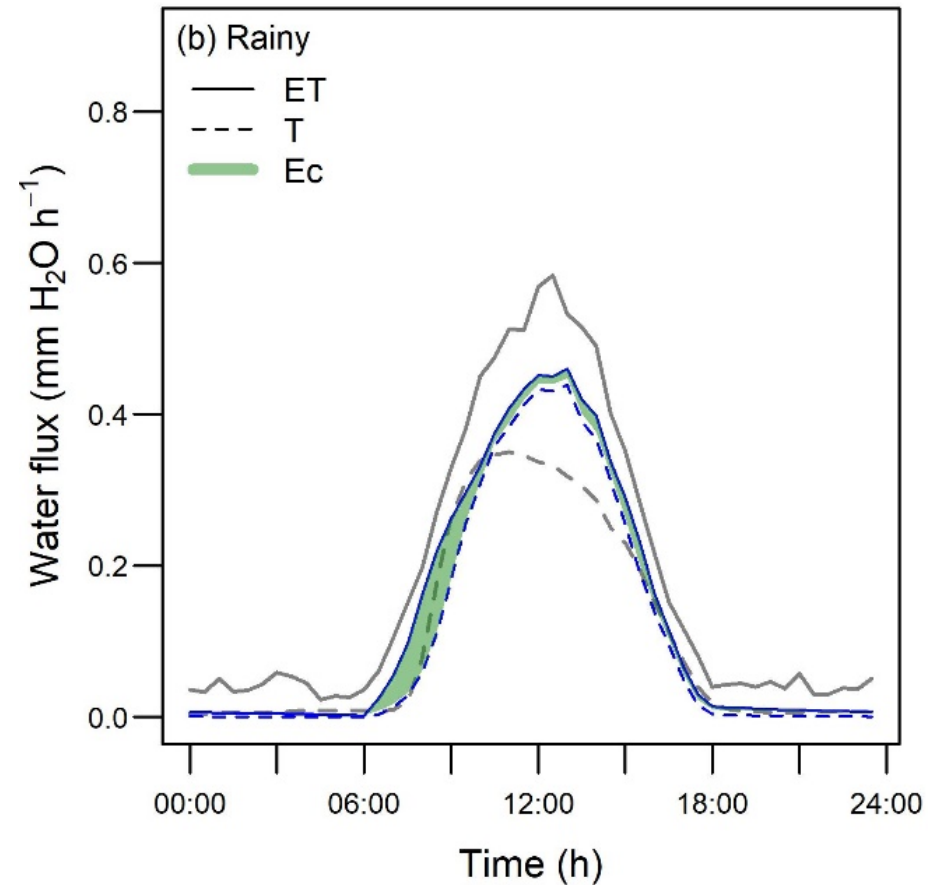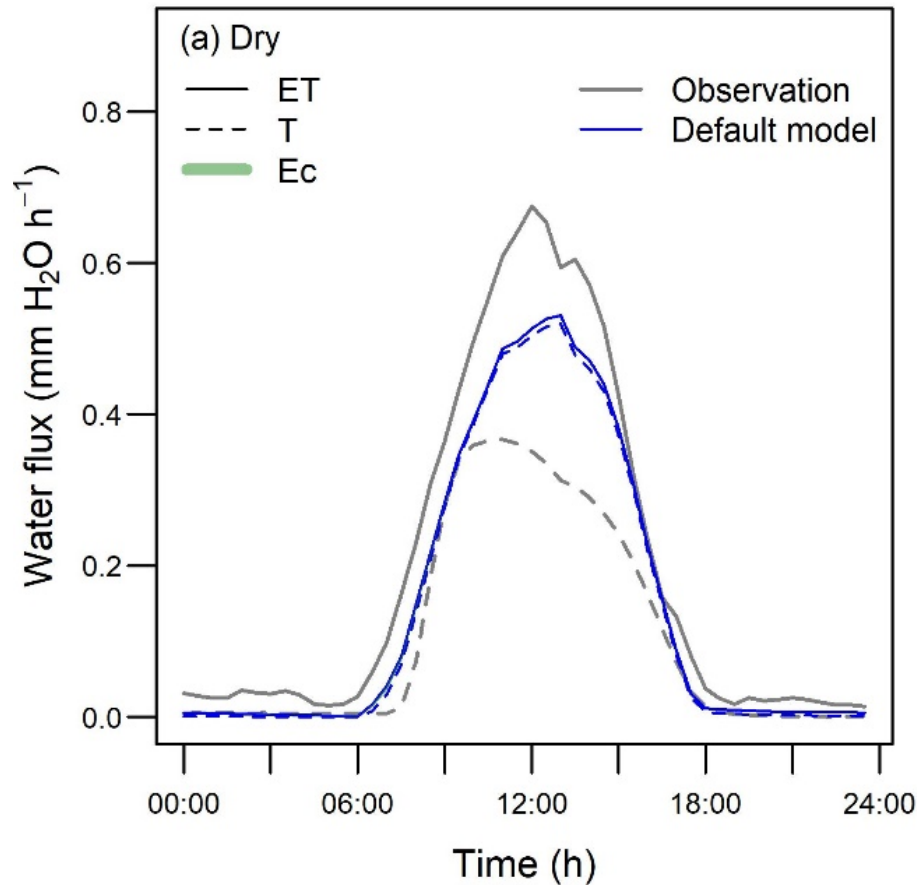

CLM4.5 forced with CRUNCEP 6-hourly data

CLM4.5 forced with GSWP3 3-hourly data

3x3min resolution, only using broadleaf evergreen forest PFT and oil palm PFT, Jan 2010

Little canopy interception and evaporation with observed half-hourly forcing

evapotranspiration (ET), transpiration (T), and canopy evaporation (E_C) for oil palm plantation

PFT-dependent canopy interception parameterization

- Interception efficiency

$$fpi = \textcolor{orange}{fpimx} \times \left(1 - e^{-0.5 \times (LAI + SAI)}\right) \qquad \text{in CLM4.5}$$

$$fpi = \textcolor{orange}{fpimx} \times \tanh(LAI + SAI) \qquad \text{in CLM5}$$

- Interception storage capacity

$$Q_{can}^{mx} = \textcolor{orange}{dewmx} \times (LAI + SAI)$$

- CLM-Palm uses PFT-dependent *fpimx* and *dewmx*, and *dewmx* is separately modelled for leaf and stem surfaces:

$$Q_{can}^{mx} = \textcolor{orange}{dewmxl} \times LAI + \textcolor{orange}{dewmxs} \times SAI$$

Sensitivity of ET partitioning to canopy interception parameterization

Fan, et al. In Preparation
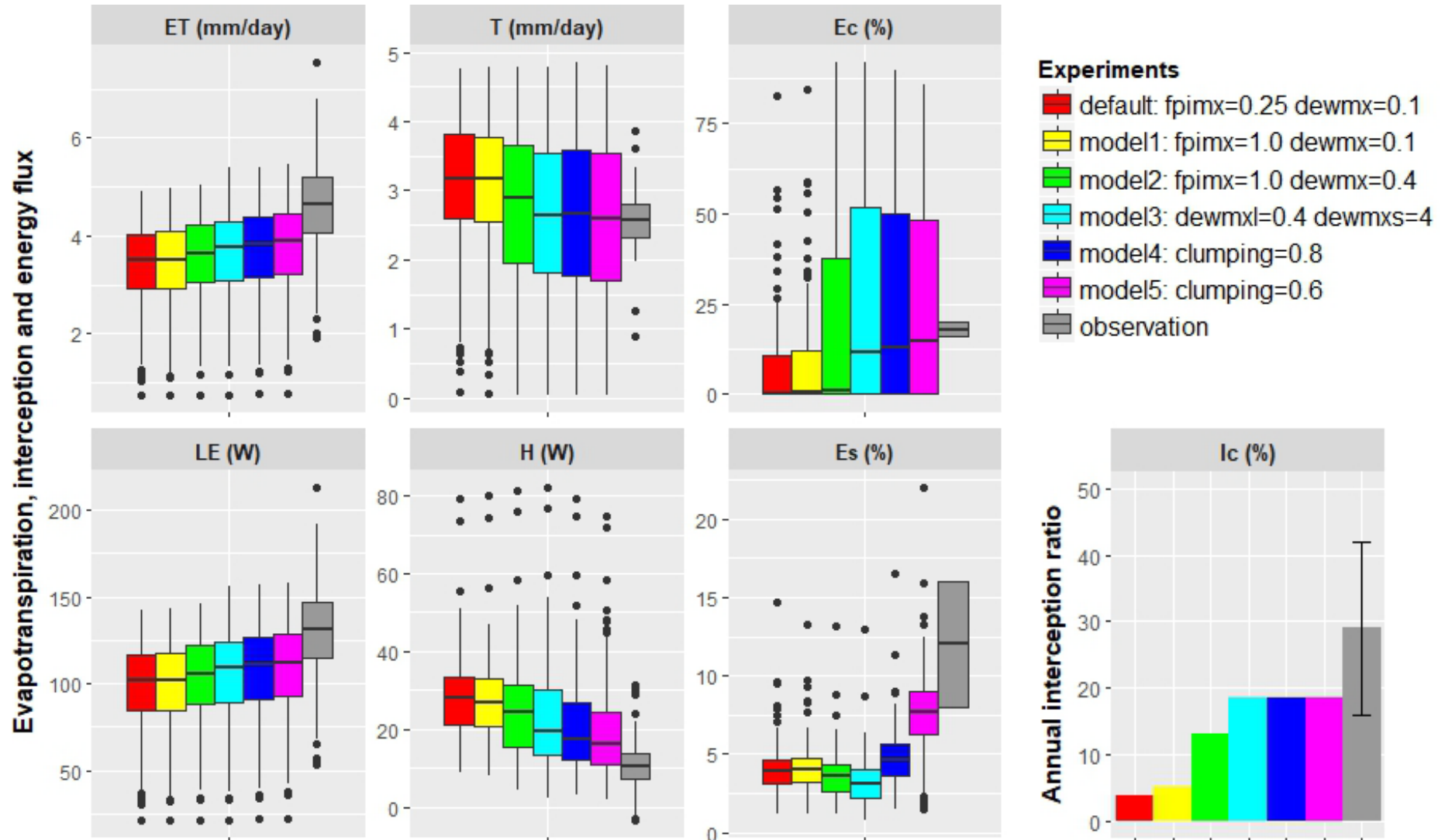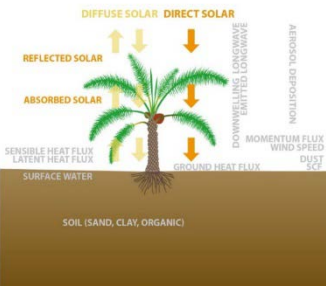
Dynamic multilayer model
for radiative transfer and photosynthesis

Two-stream approximation

CLM default big-
leaf model
(1L-2S)

optional statistical
multilayer model
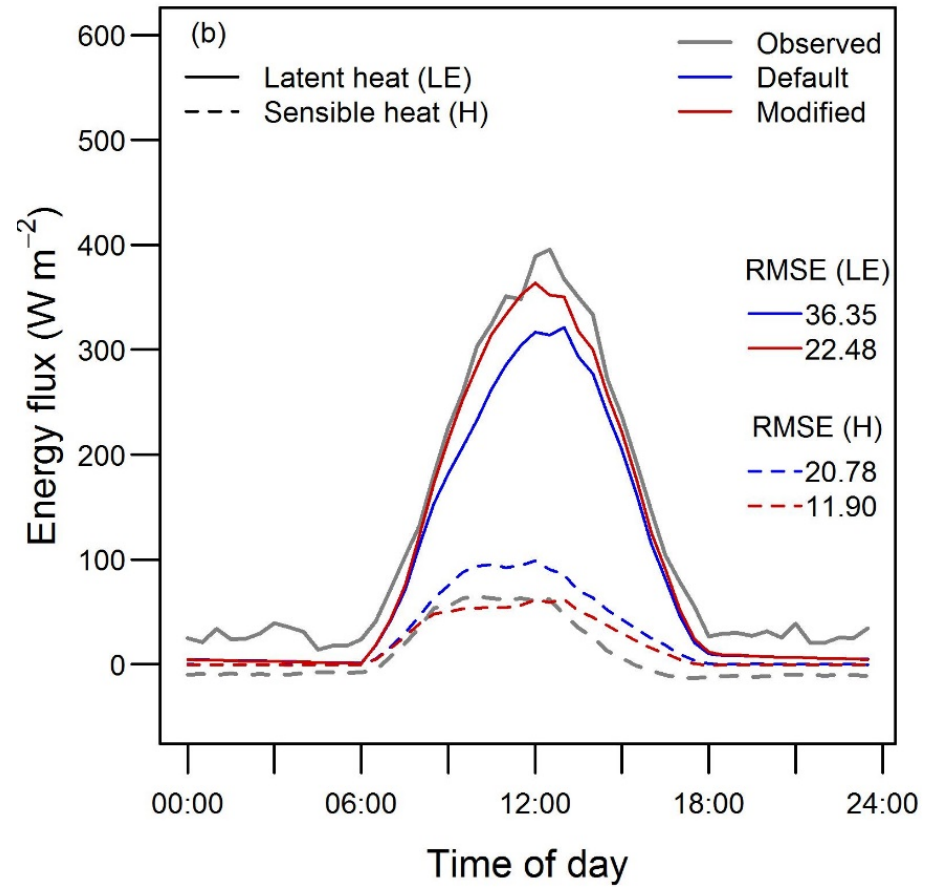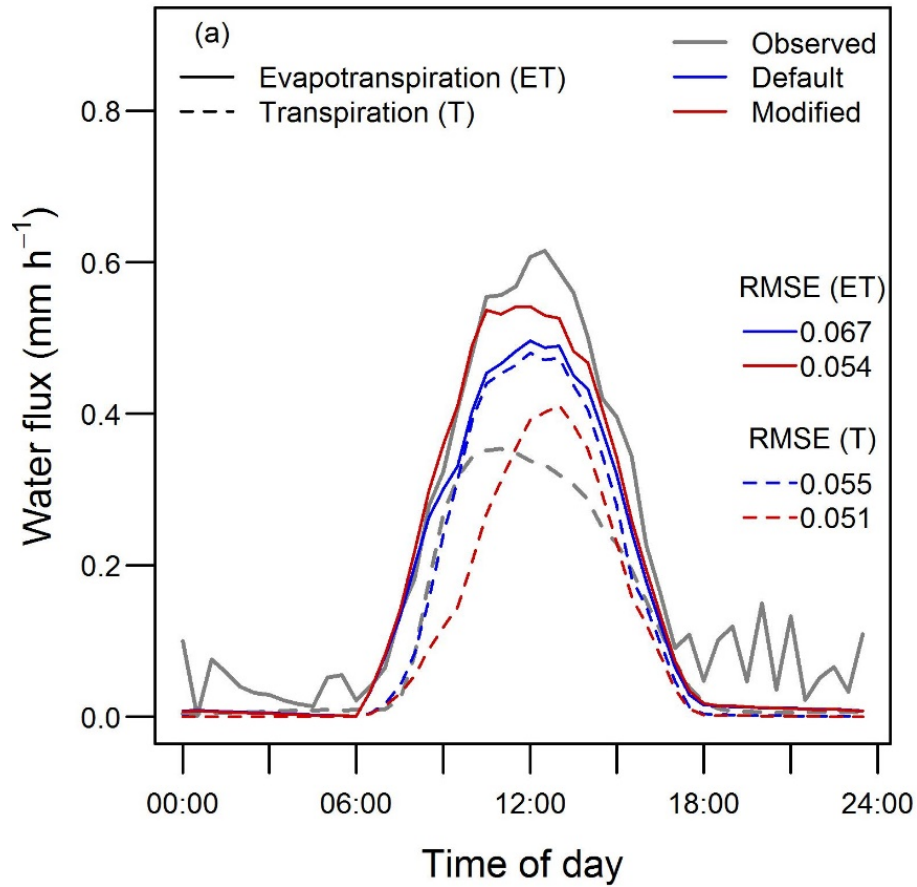(ML-2S)

Norman iterative
multilayer model
(ML-NM)

Fan, et al. In Preparation
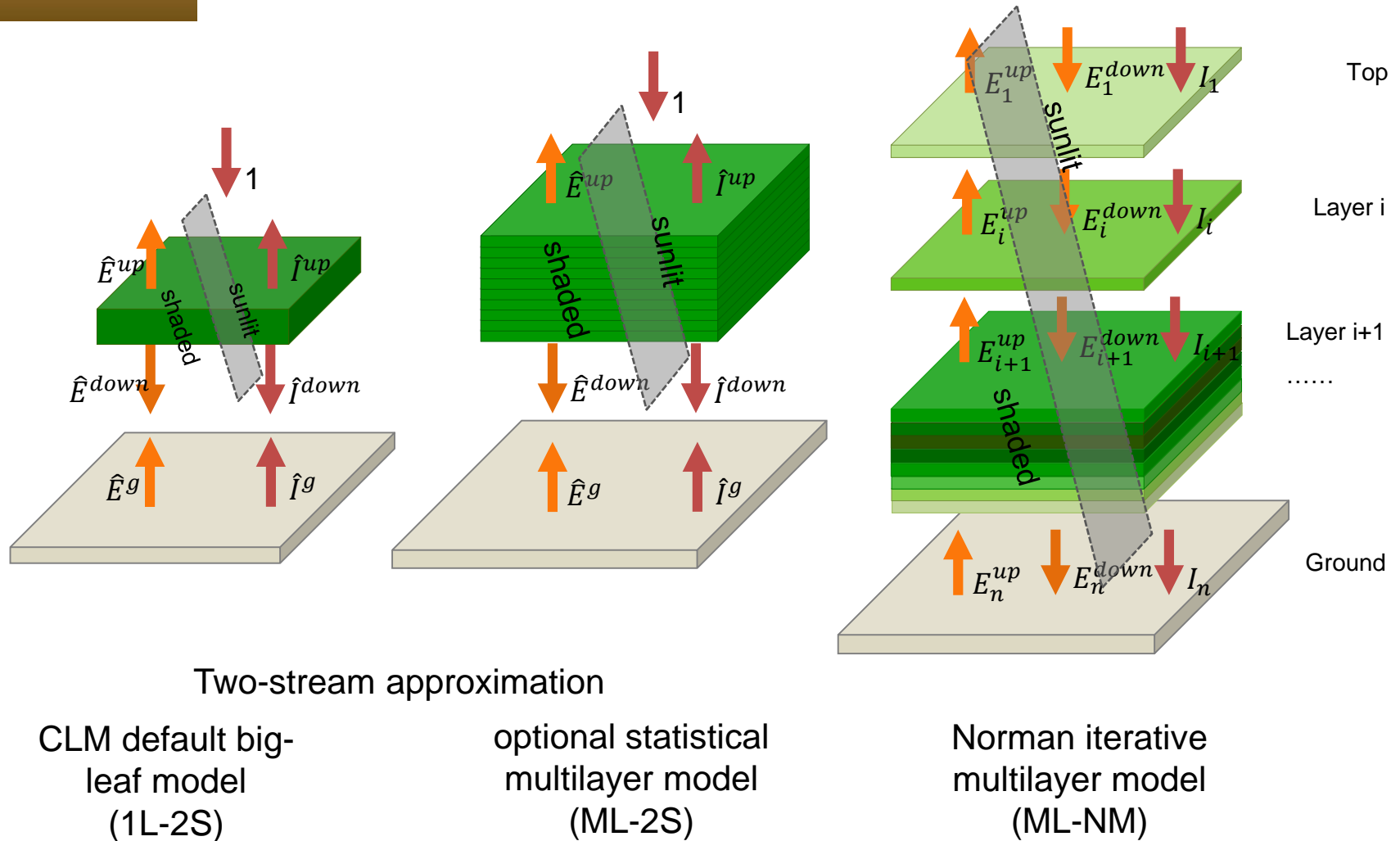
Improved diurnal pattern of ET partitioning at oil palm site
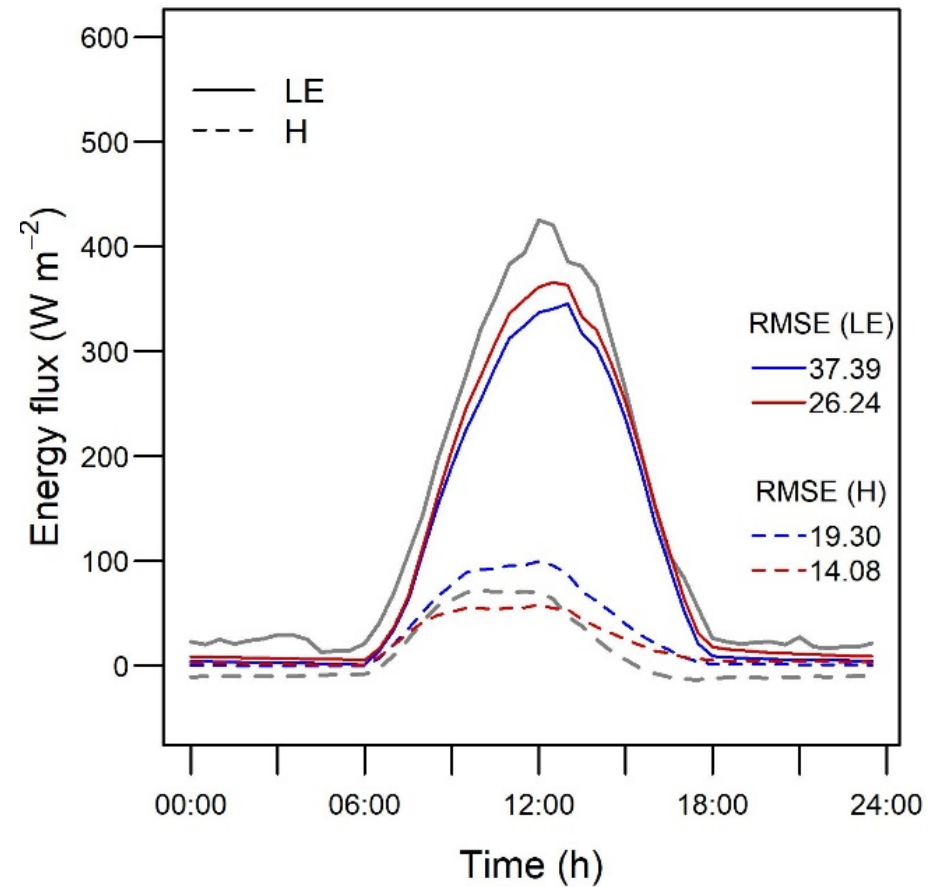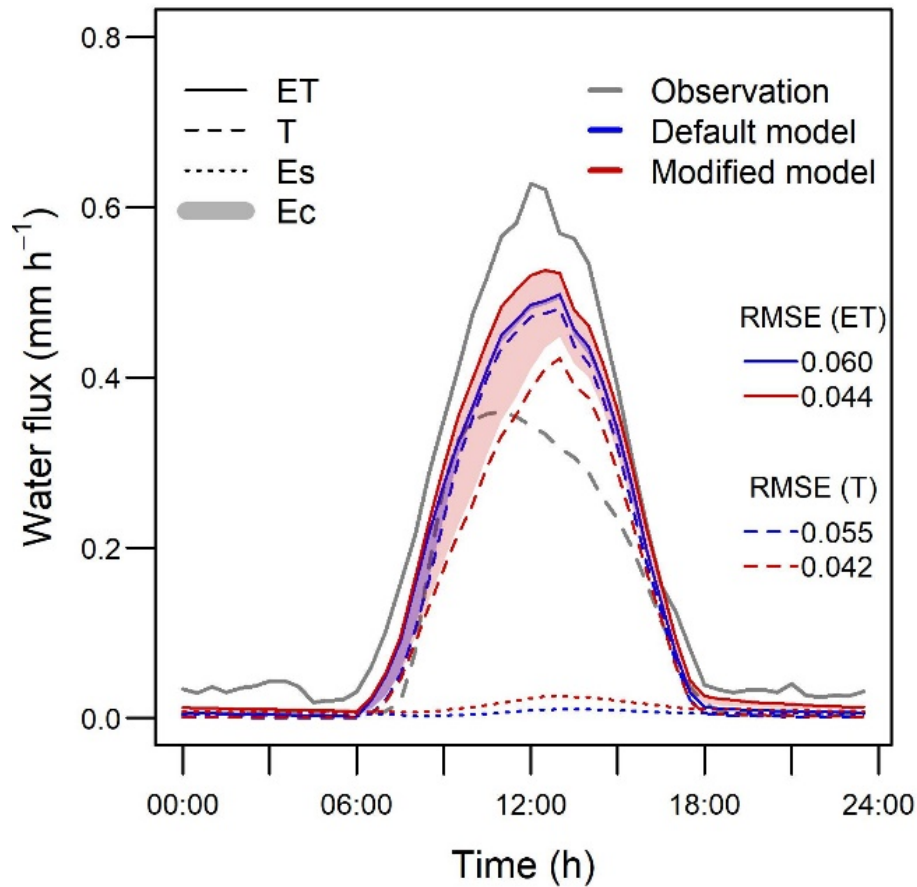
With revised canopy interception parameterization: dewmxl = 0.4 for leaf; dewmxs = 4 for stem; fpimx = 1.0; clumping = 0.6

Only rainy days

CLM5.0 with GSWP3 3-hourly forcing

ET: forests 3.1 mm/day, oil palms 2.6 mm/day

canopy evaporation — mm/s

Mean E_C 0.9 mm/day; 30%

canopy transpiration — mm/s

Mean T 1.8 mm/day; 59%
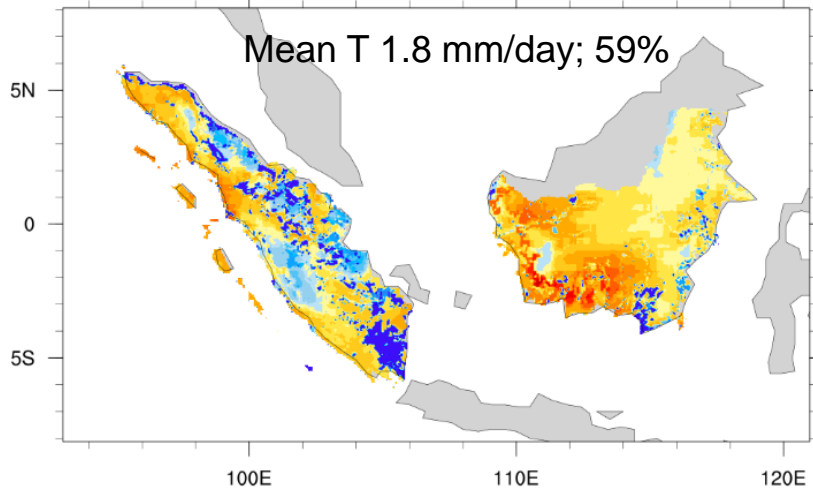
Default:
$fpimx$ = 1,
$dewmx$ = 0.1,
$fwetmx$ = 0.05

CLM5.0 with half-hourly forcing + revised interception
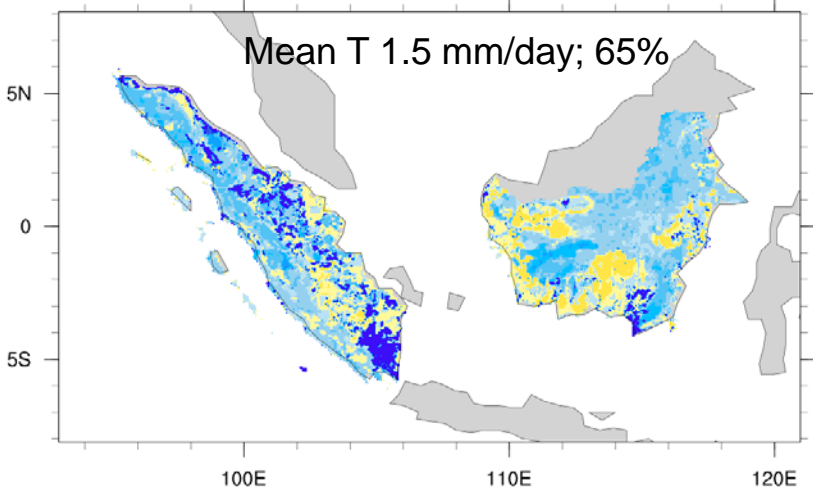
ET: forests 2.3 mm/day, oil palms 2.8 mm/day
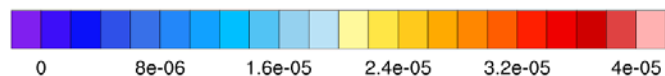
canopy evaporation — mm/s

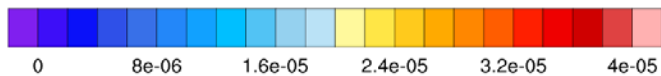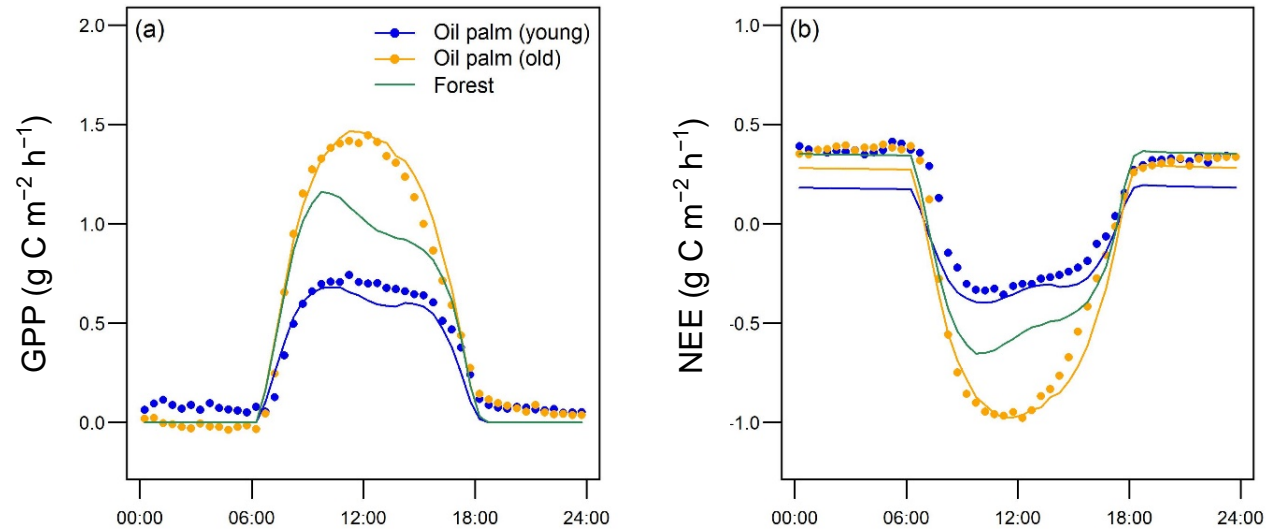Mean E_C 0.57 mm/day; 25%

canopy transpiration — mm/s

Mean T 1.5 mm/day; 65%

Revised:
$fwetmx$ = 0.1
$dewmx$ = 0.2
for forest;

$dewmxl$ = 0.4
$dewmxs$ = 4
for oil palm

Reference E_C 20%, T 64%, and E_S 16% in Wilson et al. (2001)

19

Impacts of rainforest to oil palm conversion

Fan et al. In Preparation

Impacts of rainforest to oil palm conversion
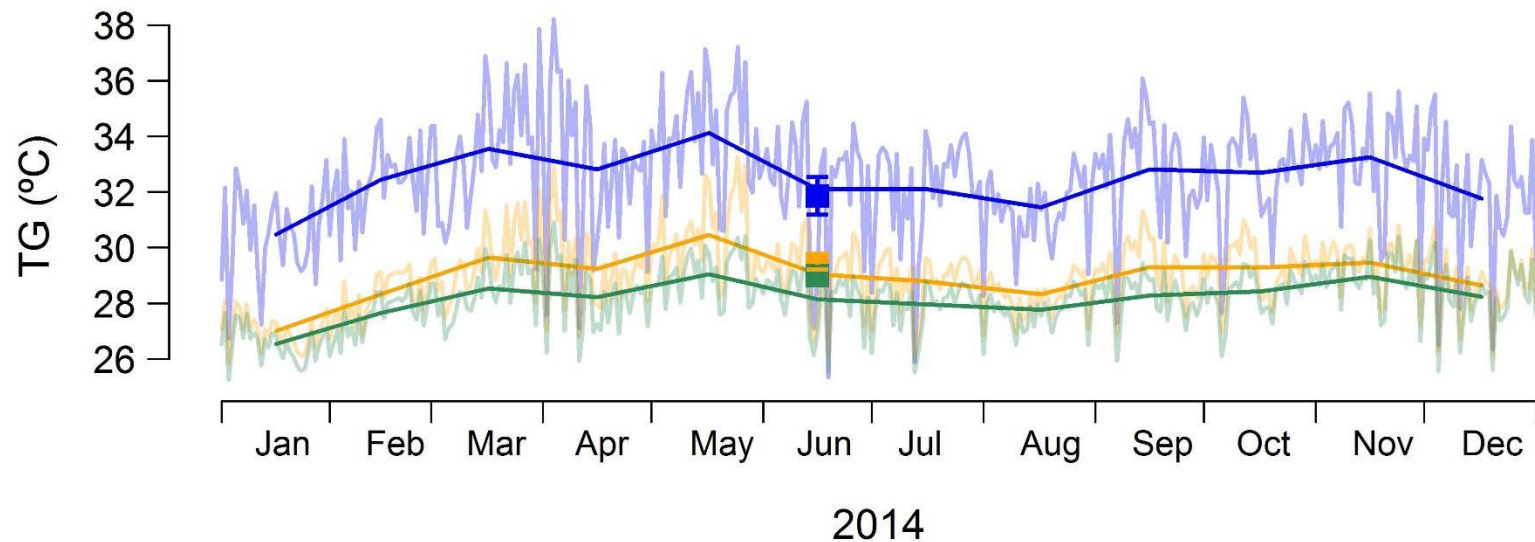
Fan et al. In Preparation
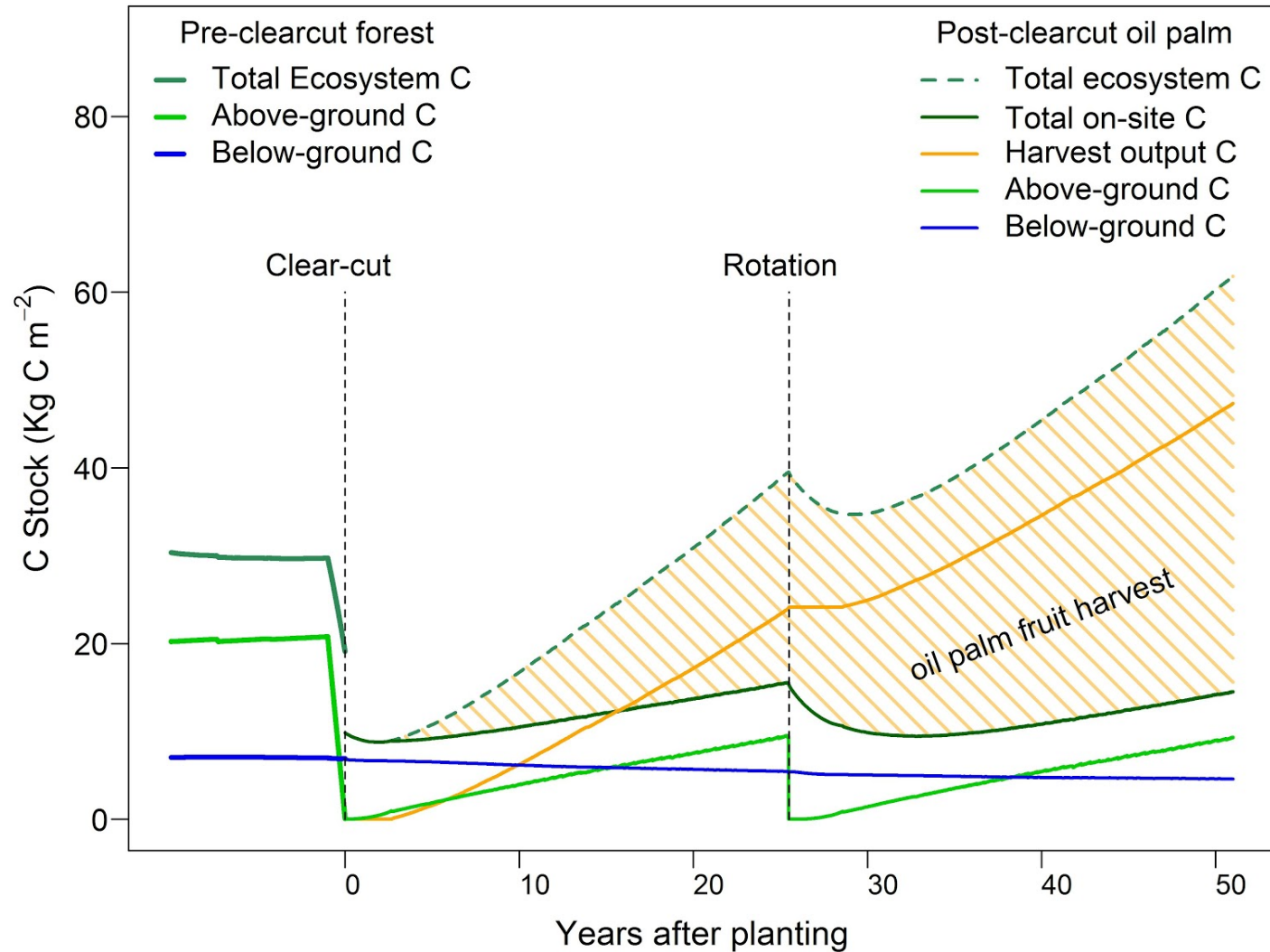
A brief summary
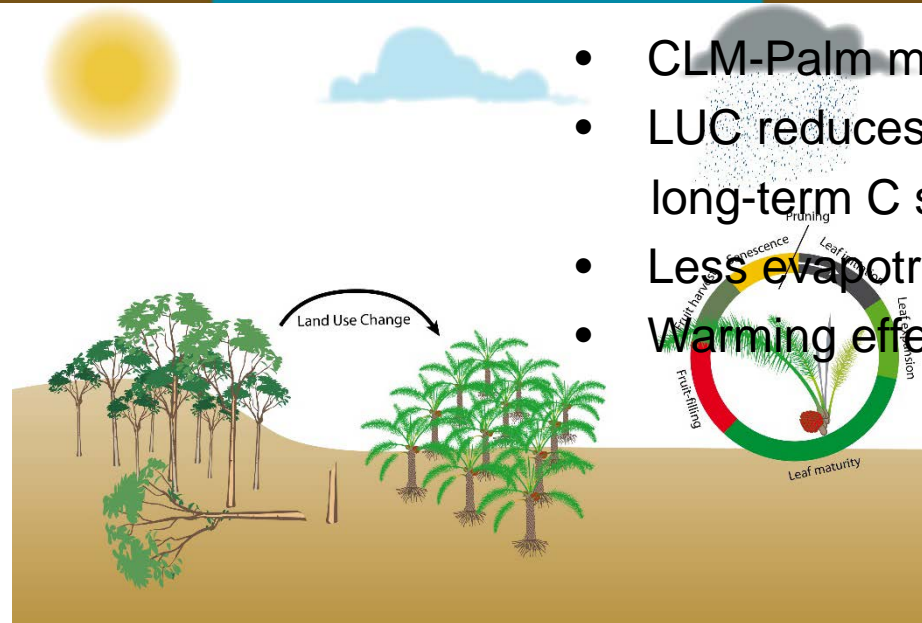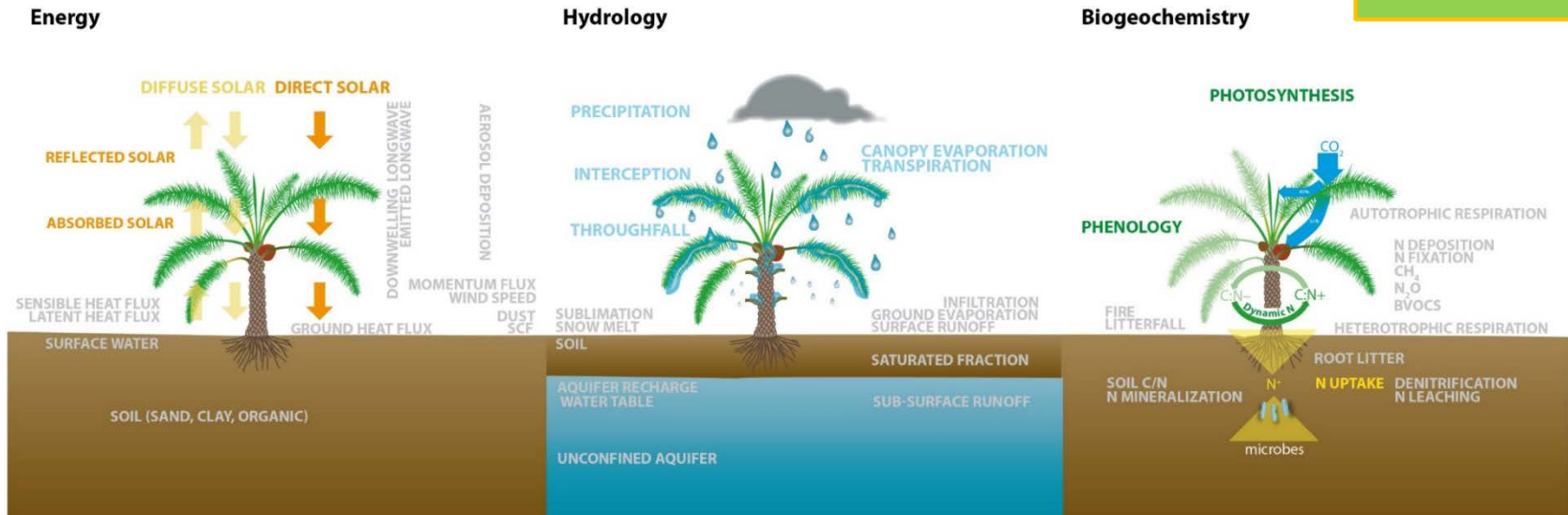
- CLM-Palm model development
- LUC reduces C stocks & long-term C sequestration
- Less evapotranspiration at young
- Warming effects throughout ages

Postdoctoral research in Norway 2016.09-now

1. Methane emission and biophysical processes in the Arctic tundra （COUP, PAGE21）

2. EU H2020: Coordinated Research in Earth Systems and Climate. Evaluating NorESM (CMIP6, LUMIP)

3. Bjerknes SKD: Low and overshoot emission scenarios – from a high to a low carbon society (LOES). Assess LULCC feedbacks

4. Bjerknes Centre Fast-track initiatives (FTI) 2018: Consequences of solar geoengineering on future agricultural sustainability in a high CO_2 world. 200kNOK. Principal Investigator

Acknowledgement

Funding from Research Council of Norway (RCN) & EU-H2020