Partitioning Evapotranspiration with the optimality hypothesis

Alison Prior &

Professor Iain-Colin Prentice

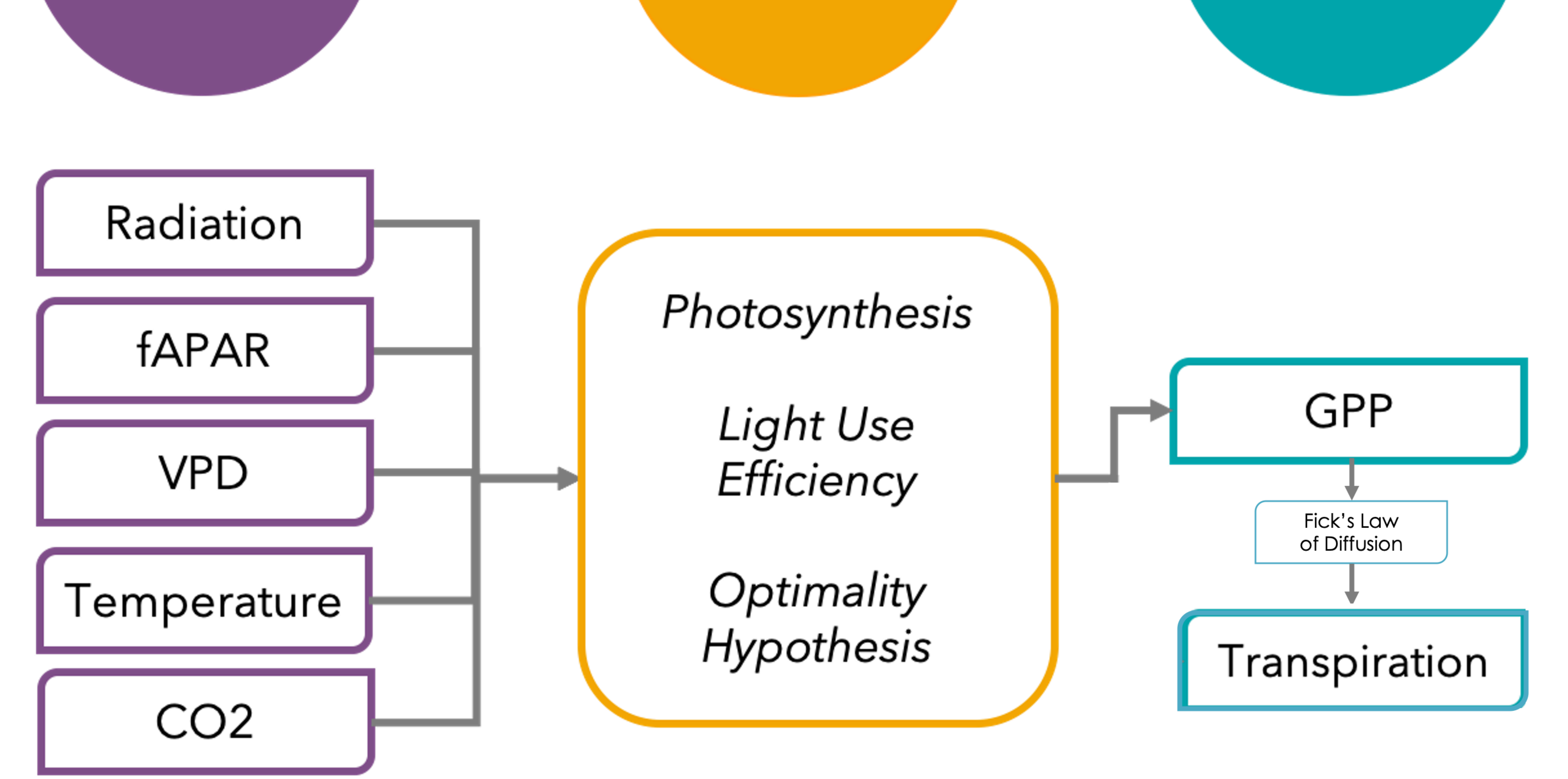
Imperial College of London

Terrestrial water–carbon cycles have to be studied as an interconnected system, given the very large impact they have on each other.

P. Gentine et al., 2019
Environmental Research Letters

The P Model

- An explicit derivation from the standard Farquhar, von Caemmerer and Berry (FvCB) **photosynthesis model**, and a clear relationship to a well-established functional form for stomatal behaviour
- A representation of physiological **CO2 effects** on photosynthesis.
- High accuracy, parameter sparse.
- Effective for **all plant functional types** and **biomes**, eliminating the need for land- cover classification or look-up tables.
- Demonstrated success in simulating flux-derived **GPP** across different biomes.


Radiation
fAPAR
VPD
Temperature
CO2
Photosynthesis
Light Use Efficiency
Optimality Hypothesis
GPP
Fick's Law of Diffusion
Transpiration

P Model Algorithm *for eager readers*

$$GPP = I_{abs} \cdot \phi_0 \cdot m\sqrt{[1 - (c^*/m)^{2/3}]}$$

$$m = \frac{(C_a - \Gamma^*)}{\left\{C_a + 2\Gamma^* + 3\Gamma^*\sqrt{[1.6 \cdot \eta^* \cdot D_0 \cdot \beta^{-1}\,(K + \Gamma^*)^{-1}]}\right\}}$$

$$A = GPP = gs \cdot ca(1 - \chi)$$

$$\mathrm{T} = 1.6 \cdot gs \cdot D$$

m *coefficient*	the substrate limitation term determines the reaction of stomatal conductivity to changes in VPD
φ_0	intrinsic quantum yield (1.02 g C / mol),
I_{abs}	absorbed photosynthetic photon flux density (PPFD, mol /m²/s),
Γ^*	photorespiratory compensation point (Pa),
K	effective Michaelis-Menten coefficient of Rubisco (Pa),
η^*	viscosity of water relative to its value at 25 degrees Celsius,
$\beta \approx 240$	from constant C in the equation for optimal leaf internal to external CO2 ratio (χ_0),
$c^* \approx 0.41$	estimated from observed J_{max}: Vc_{max} ratios proportional to the unit carbon cost for maintenance of electron transport capacity.
A	is assimilation of carbon dioxide by the leaf, or GPP (mol/m²/s)
gs	is stomatal conductance of CO_2 (mol/m²/s),
χ	is the ratio of leaf internal (c_i) to external (c_a) CO_2 partial pressure (-),
T	is transpiration (mol/m²/s),
D	is the leaf to air vapour pressure deficit (mol/mol).

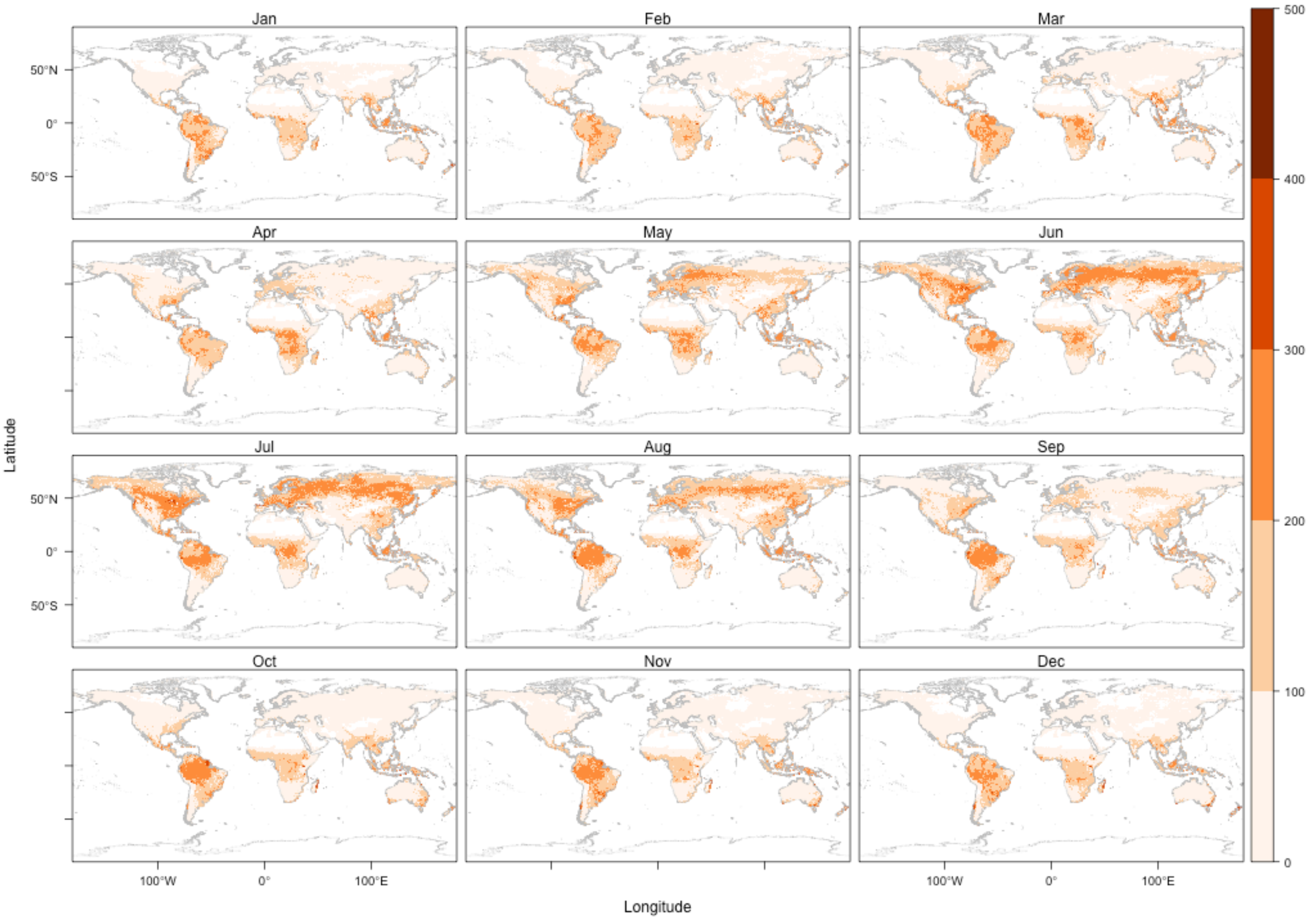
There is hope
that one may be able to
assess canopy photosynthesis
using a **light use efficiency**
model & remote sensing data,
then use this information to
develop spatial fields of
surface conductance &
evaporation.

Denis Baldocchi, 2020
Global Change Biology

Calculating Global Transpiration & GPP

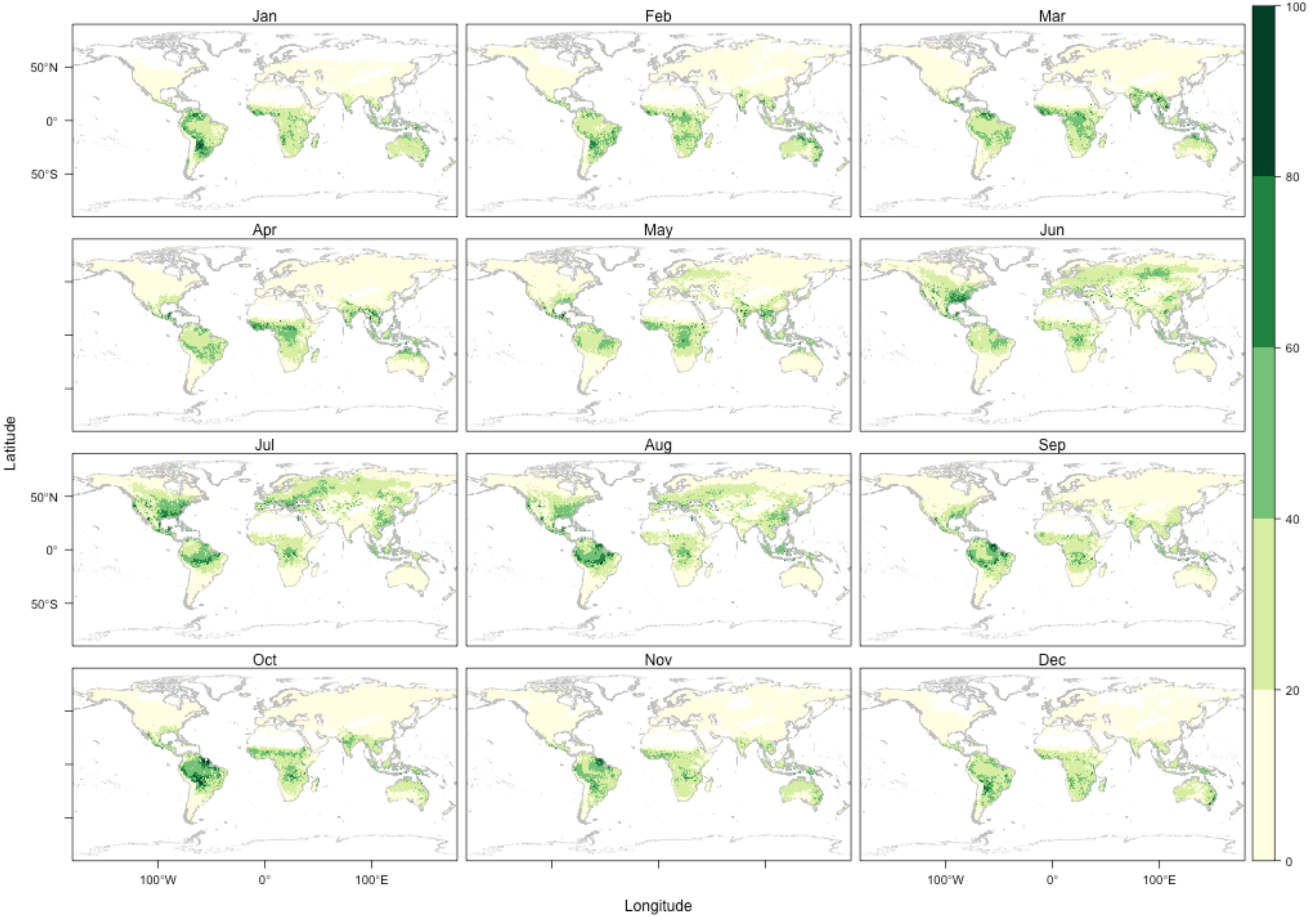
- The P model effectively couples carbon and water cycles
- Determines water loss (transpiration) and carbon uptake (GPP) via optimality hypothesis, accounting for stomatal regulation.
- Global P Model run with CRU meteorological data & MODIS fAPAR

P Model
GPP Results
grams Carbon /month
Sample year: 2016



1982-2016
Inputs: CRU, MODIS fAPAR
Res: 0.05° x 0.05 °,
dekadal / monthly / annual

P Model
Transpiration Results
Sample year: mm /month
2016

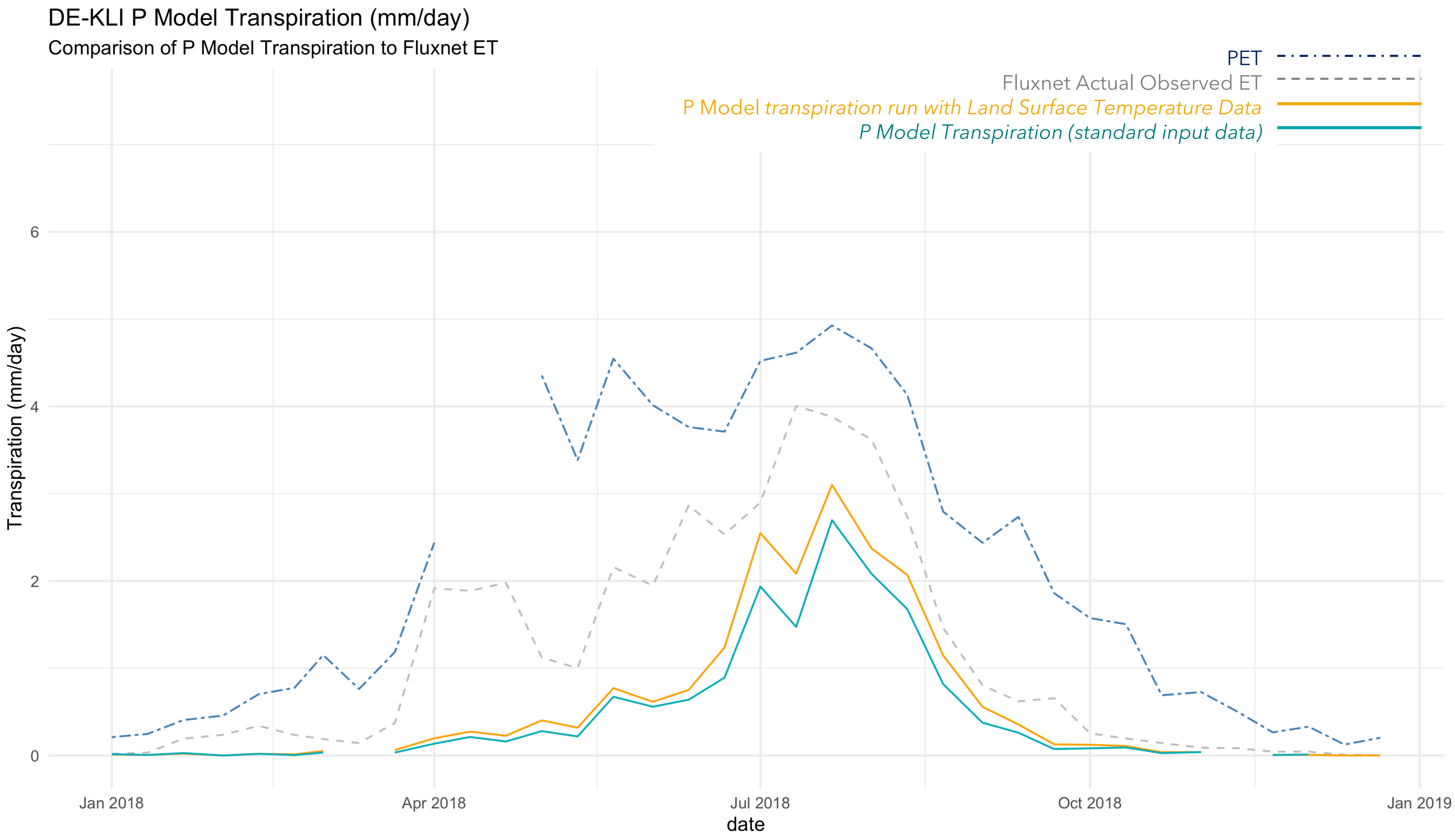


1982-2016
Inputs: CRU, MODIS fAPAR
Res: 0.5 x 0.5
dekadal / monthly / annual

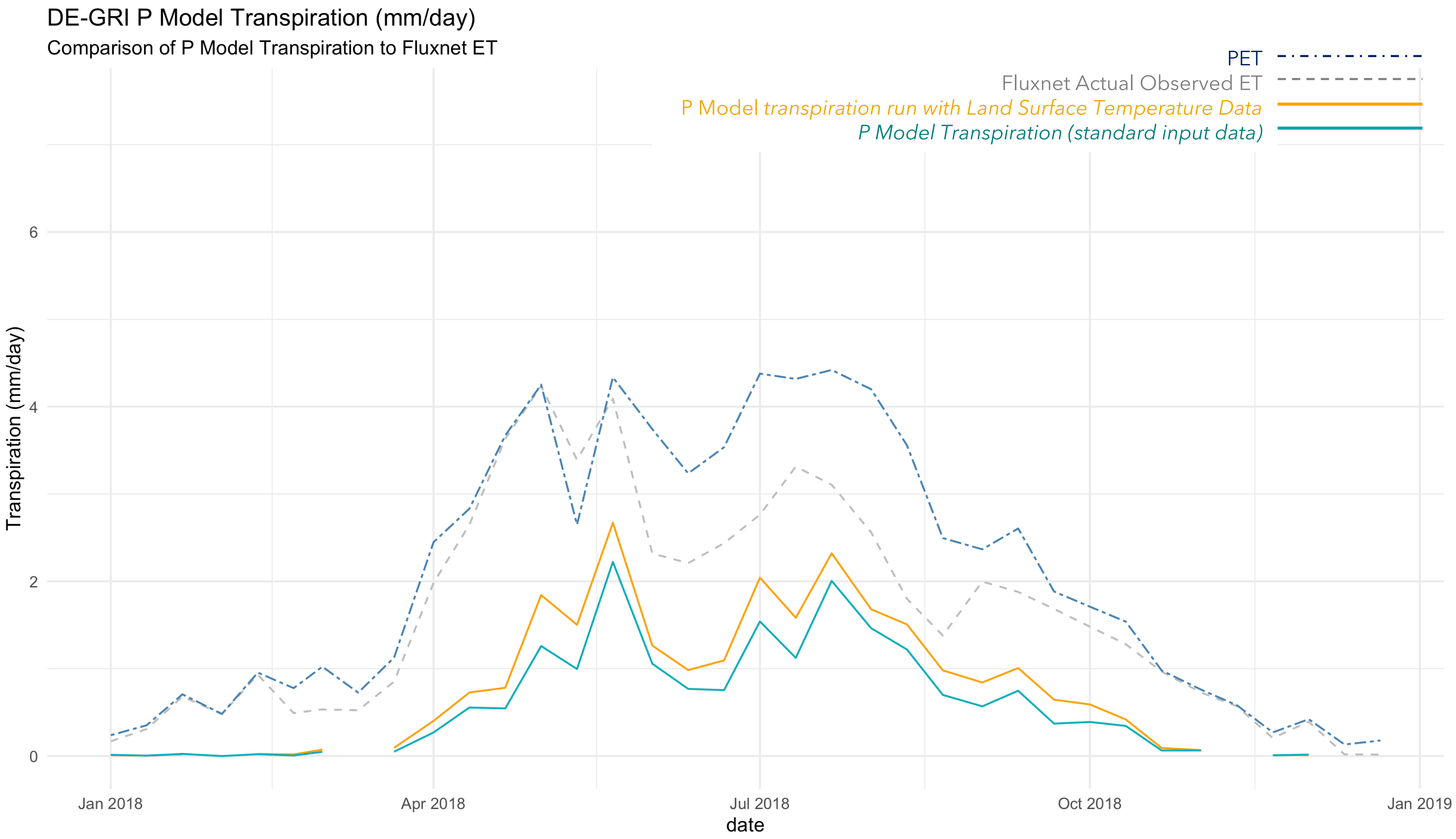
P Model & Sentinel 3 (2018 trial)

- In order to obtain more recent input data we have tested the P model with Sentinel 3
- Ocean Land Colour Instrument (OLCI) fAPAR
  - Land Surface Temperature
  - Higher resolution (300 m) than previously-used satellite products
- P Model run at 28 sites across different biomes for the year 2018
- Sample results shown in the next few slides
- Potential for recent global satellite-based transpiration and GPP
- Further testing and statistical analysis to be conducted

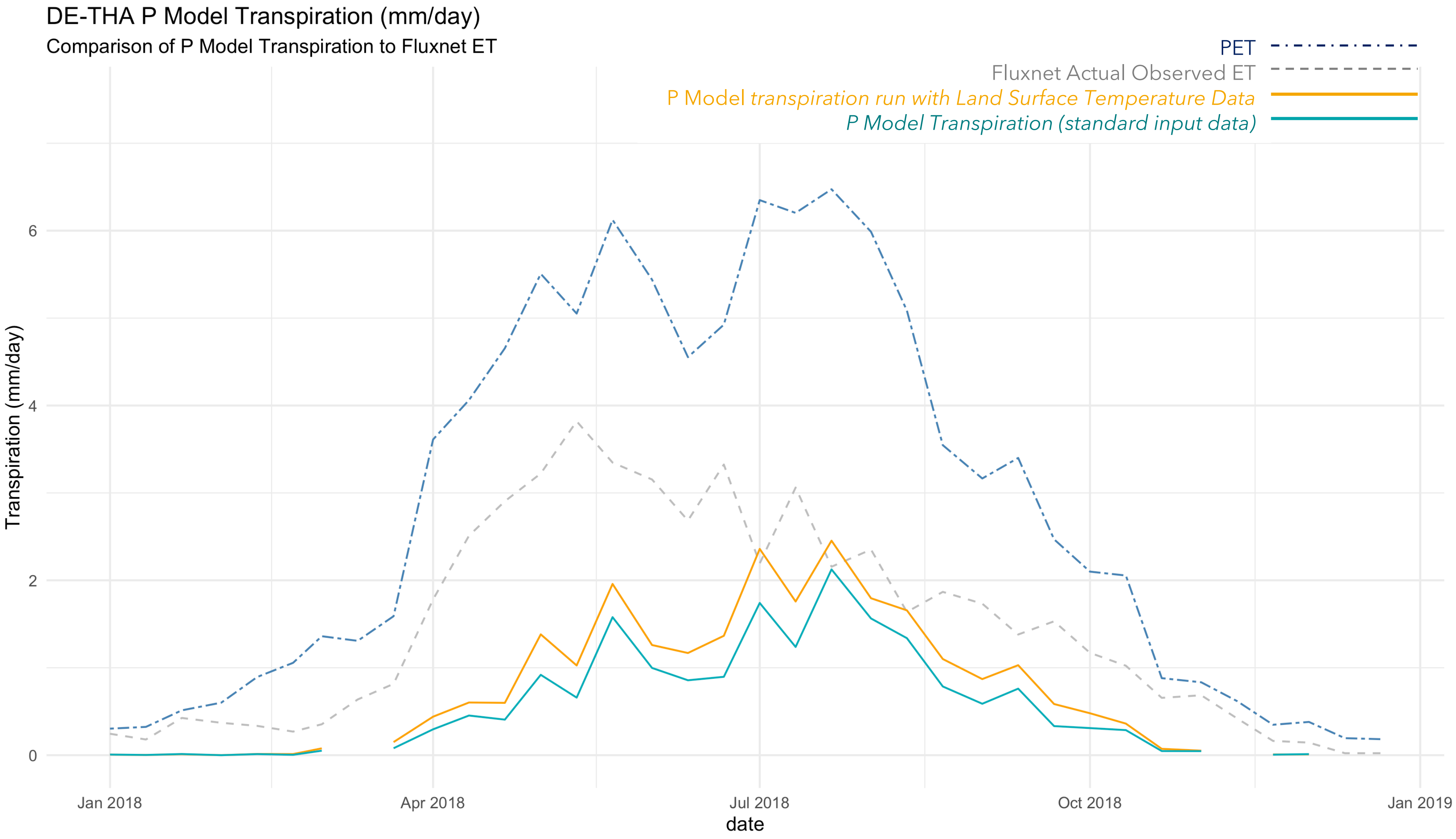
P Model **Transpiration**



P Model **Transpiration**



P Model **Transpiration**

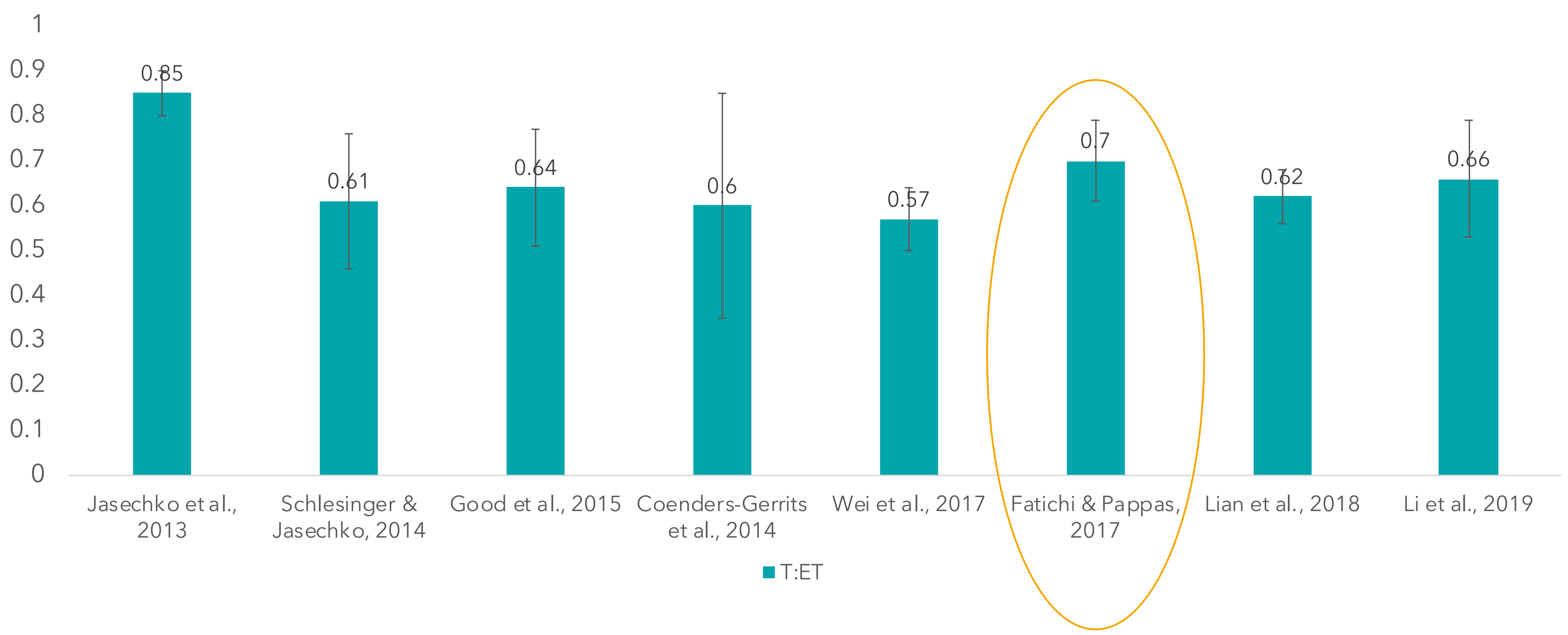


Partitioning of ET into E and T has been of interest since the earliest stages of crop, soil and forest modeling and observations

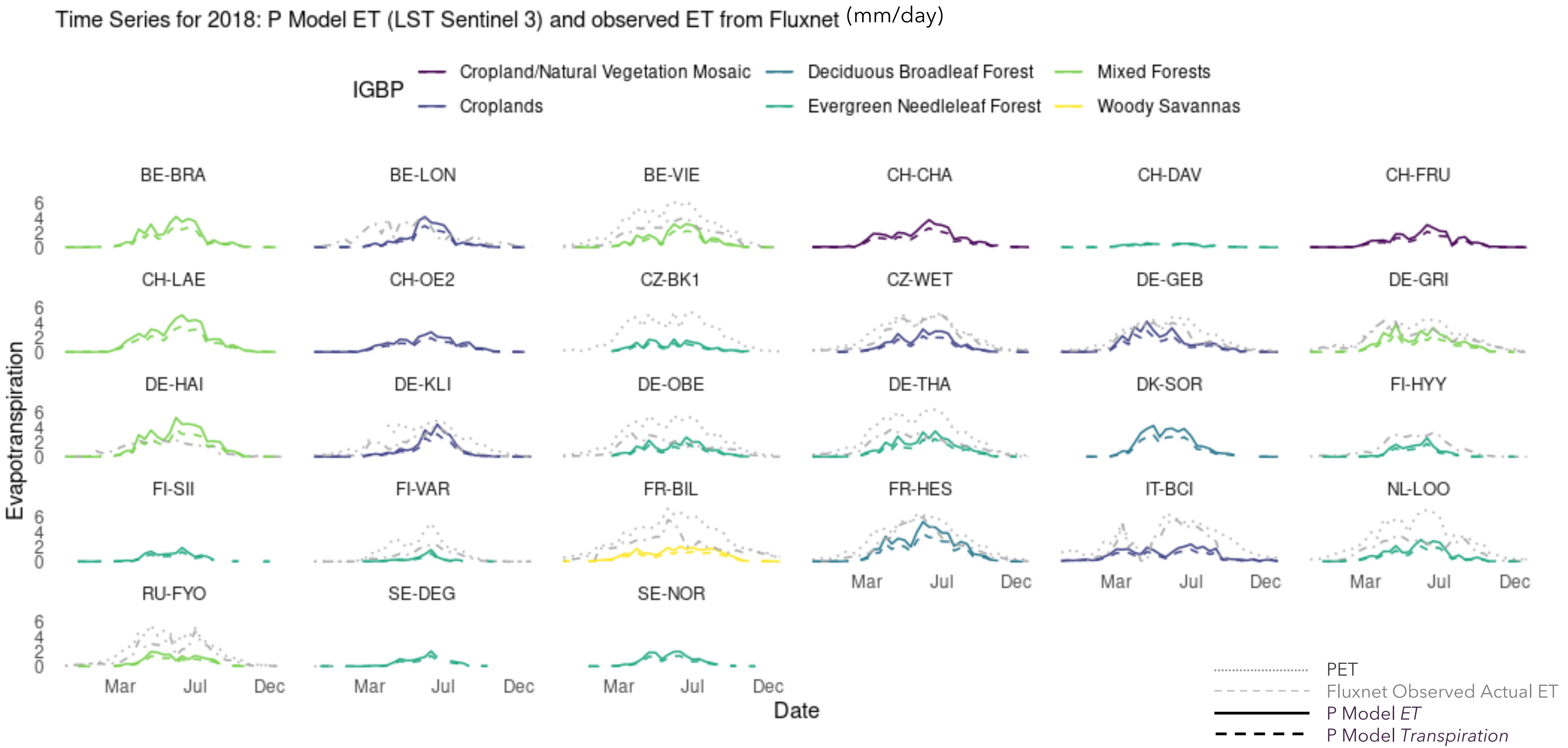
Anderson et al., 2018

Variability in global estimates of T:ET ratios

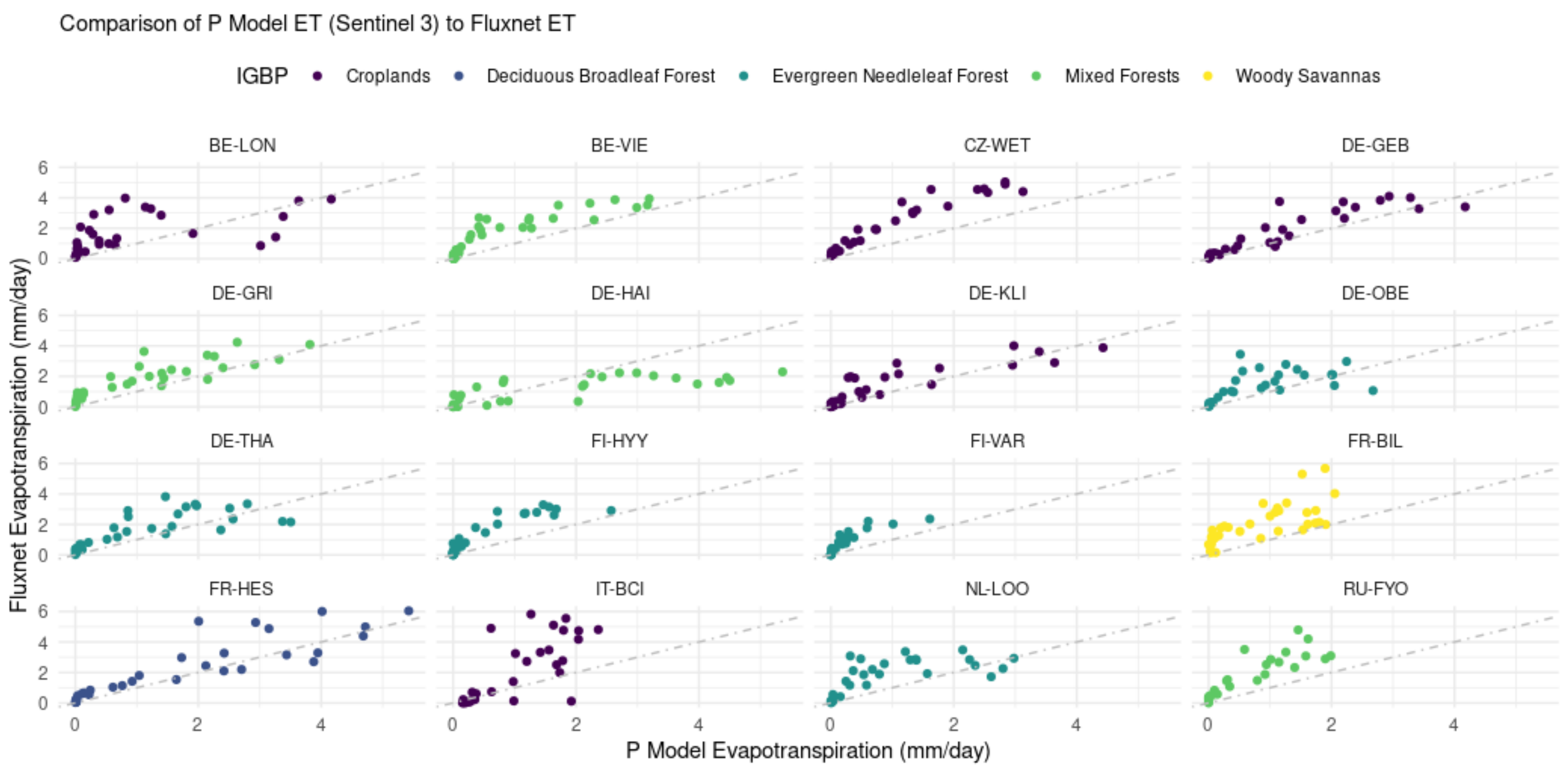
P Model ET estimates have followed the methodology of Fatichi & Pappas as an initial step =>
T:ET ratio fixed at 0.7



P Model **Evapotranspiration**



P Model **Evapotranspiration**



Does optimality improve ET partitioning?

Modelling transpiration:

- Plant physiological (bottom-up) method for modelling transpiration, differs to usual method of partitioning of ET from the top down.
- Calculates water loss from canopy (transpiration) as plants regulate stomata to optimise carbon uptake and minimise water loss.
- By running global analysis we can further investigate the relationship between T and ET under various conditions.

Can the P model help us partition ET?

Yes -->

Effectively predicts transpiration at 100+ fluxnet sites

Provides global transpiration based on sources such as CRU, Sentinel 3 and ECMWF

Couples carbon and water cycles to provide greater insight into vegetation response to environmental change

Global transpiration based on plant physiological processes

Model built exclusively with scientific first principles; photosynthesis, light use efficiency and the optimality hypothesis.

Provides insight into how T:ET is partitioned spatially and temporally when compared with total ET measurements and models

Challenges

Further work required to effectively account for soil moisture in model.

Further investigation into model performs in various climatic zones.

Validation of transpiration -- remains a challenge

- Eddy covariance flux towers provide latent heat exchange (ET), not transpiration.
- Transpiration measurements such as sapflux cannot be readily compared with canopy / global transpiration.

To create a « useful » product, T must be 'upscaled' to ET, thus requiring a first principles approach for soil evaporation and interception.

Paschalis T:ET ratio employed for preliminary studies, but the accuracy of such a fixed ratio must be more widely tested.

Further research

- **Benchmark P Model Transpiration against ET data products, e.g.**
  - GLEAM / CMRSET / SSEBop / MODIS

- **Conduct water balance assessment of P-Q(-R?)**
  - Major basins from each continent
  - GRDC river discharge
  - CHIRPS rainfall data

- **Budyko framework**
  - **Evaporation Index (AET/P) : Aridity Index (PET/P)**
  - Testing of P model with budyko equation to determine fit and model performance

- **Further analysis with global model**
  - Testing with other global inputs to improve spatial and temporal resolution
  - Additional evaluation and testing of methods for incorporating soil moisture
  - Methodology for Evaporation and Interception modelling
  - Statistical analysis of transpiration by vegetation type

P Model
Further reading

Letter | Published: 04 September 2017

Towards a universal model for carbon dioxide uptake by plants

Han Wang, I. Colin Prentice, Trevor F. Keenan, Tyler W. Davis, Ian J. Wright, William K. Cornwell, Bradley J. Evans & Changhui Peng

Nature Plants 3, 734–741(2017) | Cite this article

Geosci. Model Dev., 13, 1545–1581, 2020
https://doi.org/10.5194/gmd-13-1545-2020

Geoscientific Model Development
Open Access
EGU

P-model v1.0: an optimality-based light use efficiency model for simulating ecosystem gross primary production

Benjamin D. Stocker[1,2,3], Han Wang[4], Nicholas G. Smith[5], Sandy P. Harrison[6], Trevor F. Keenan[7,8], David Sandoval[9], Tyler Davis[9,10], and I. Colin Prentice[9,4,11]

P Model R packages:
- stineb/rpmodel
- dsval/rpmodel-grid-dev/

Research funded by ERC project: **Reinventing Ecosystem And Land-Surface Models (REALM)**

More information:

a.prior18@imperial.ac.uk
Prentice Lab
Department of Natural Sciences
Imperial College of London

Imperial College London

REALM
'Re-inventing Ecosystem And Land-surface Models

erc
European Research Council
Established by the European Commission