Using the **Net Carbon Profit** for optimizing vegetation properties along a precipitation gradient

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Introduction

- TBMs Today
- Vegetation Optimality
- Hypotheses

Methods

- North-Australian Tropical Transect
- Vegetation Optimality Model

Results

- Model comparison
- Foliage costs
- Rooting depths
- Water transport costs

Conclusions

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Supported by the Luxembourg National Research Fund (FNR) ATTRACT programme (A16/SR/11254288)

TERRESTRIAL BIOSPHERE MODELS TODAY

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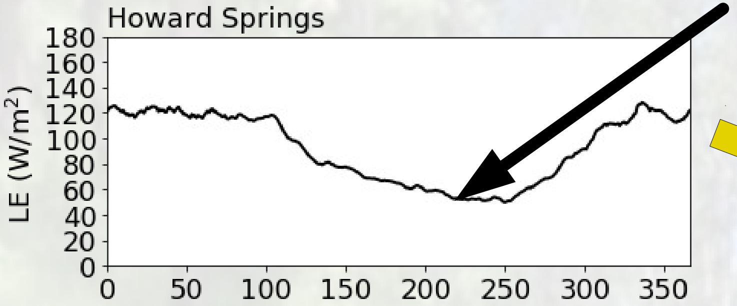
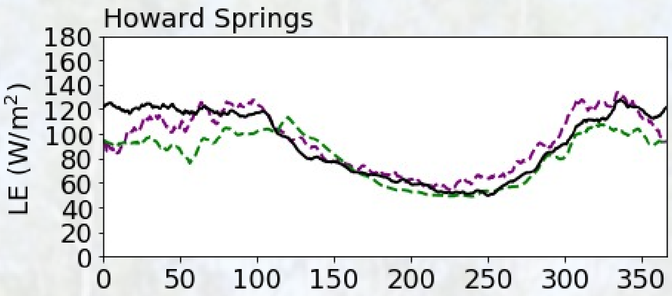
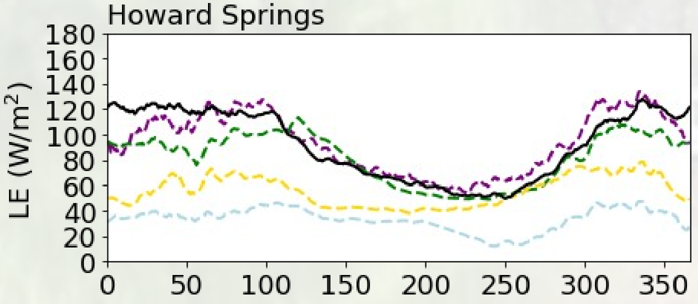
Some data of the latent heat flux, Howard Springs, Australia



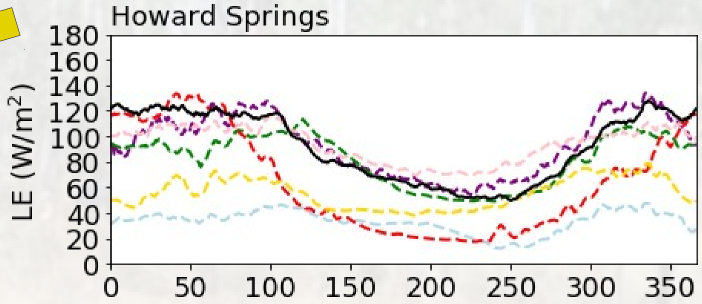
Some models seem pretty good!

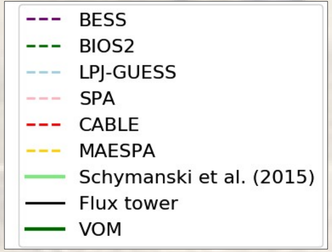


Others underestimate seasonality



And some overestimate seasonality





Many different outcomes for different reasons!

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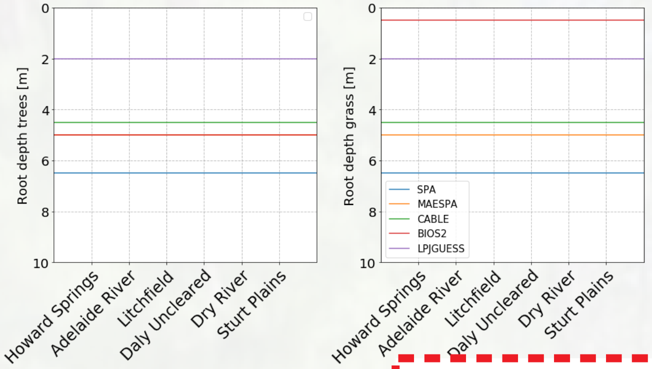
Model data from:
Whitley et al. (2015): Biogeosciences 13

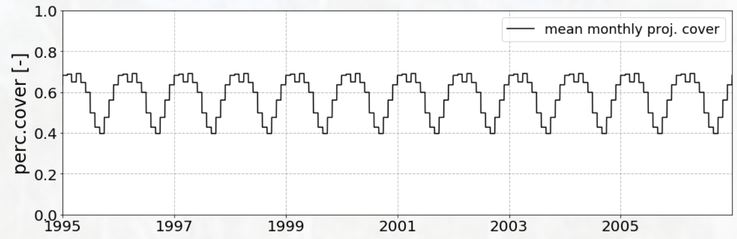
TERRESTRIAL BIOSPHERE MODELS TODAY

What's going on... ?

Models use Plant Functional Types and prescribe constant rooting depths ...



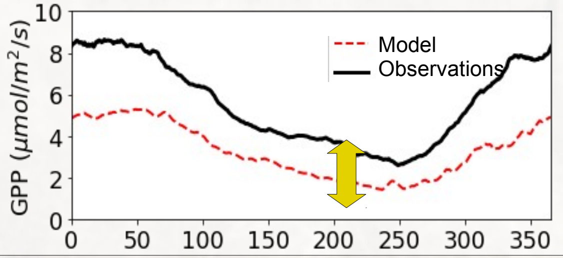
Vegetation cover and leaf area index are often prescribed on mean monthly remotely sensed data...



Relying on data and past observations !!!

Models often assume freely draining conditions...

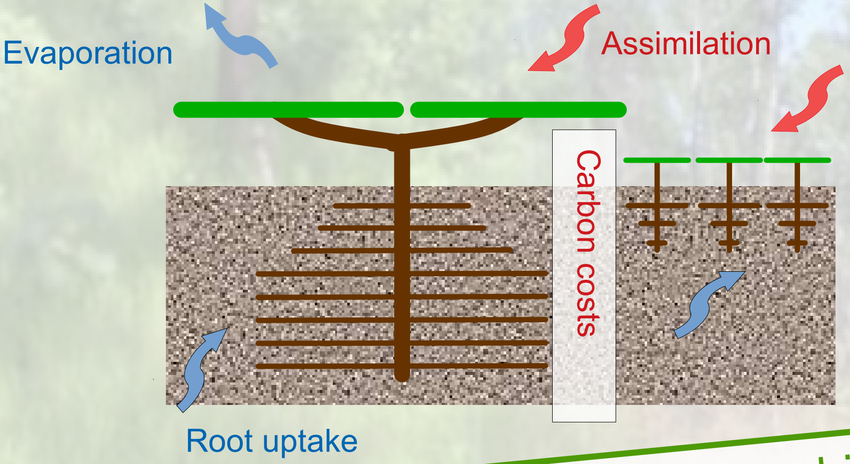
Unknown parameters often tuned for specific conditions or calibrated on observations...



VEGETATION OPTIMALITY

Net Carbon Profit :

Total difference of carbon uptake by photosynthesis and carbon costs of the system



Vegetation Optimality Model

Optimizes vegetation properties to maximize NCP

No vegetation data needed

No calibration on historical data

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HYPOTHESES

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- Conventional models capture the temporal and spatial variation of carbon and water fluxes better compared to the optimality-driven model.

Go to results →

- Optimality-based dynamics of vegetation cover will lead to worse reproduction of fluxes compared to using mean monthly vegetation cover values for each site obtained from remote sensing time series.

Go to results →

- Optimality-based rooting depths will not result in better reproduction of carbon and water fluxes compared to a prescribed, homogeneous rooting depth.

Go to results →

- Re-calibration of the costs for the water transport system, i.e. costs for the vascular system in roots, stems and branches, at each site will not result in a large variation of the cost parameter for these costs.

Go to results →

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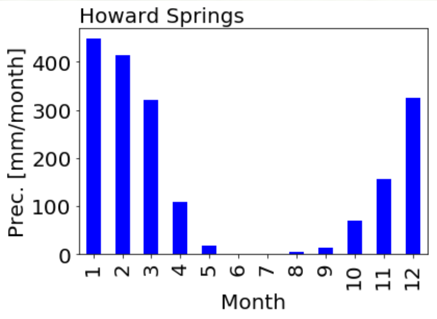
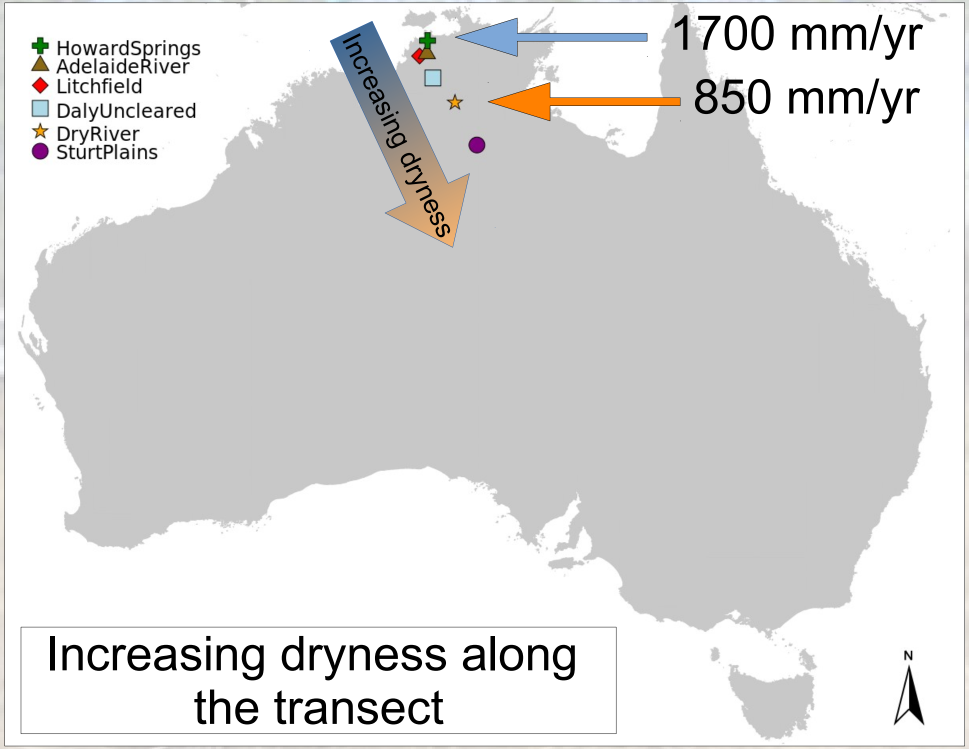
NORTH AUSTRALIAN TROPICAL TRANSECT

- Mean annual rainfall: 500-1800 mm
- Pronounced wet season: Nov-Feb
- Evergreen trees + seasonal grass
- Flux towers for evaporation and CO_2-fluxes

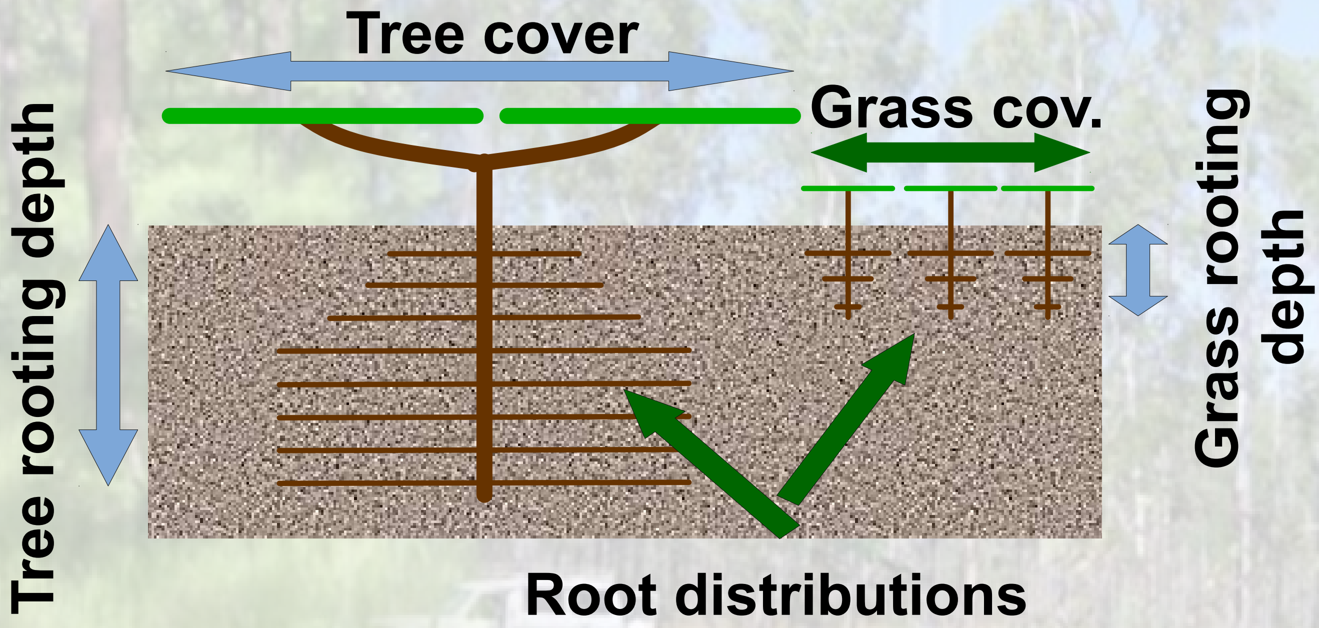


Strong seasonal signal in precipitation



Increasing dryness along the transect

VEGETATION OPTIMALITY MODEL



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Optimized constants

- Tree cover fraction
- Tree rooting depth
- Grass rooting depth
- Water use strategies

Dynamically optimized variables:

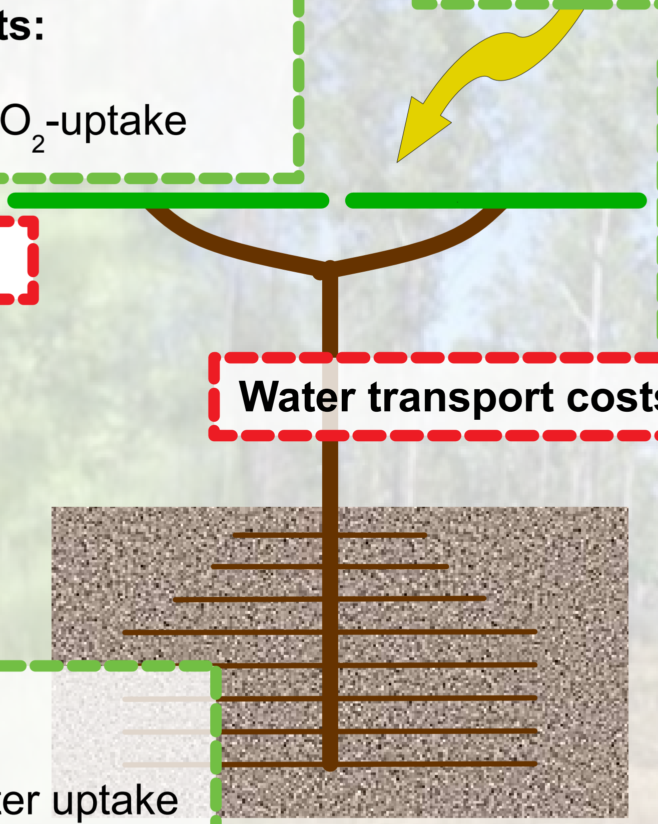
- Grass cover fraction
- Photosynthetic capacity
- Stomatal conductances
- Fine root surface area

NET CARBON PROFIT

Assimilation

Foliage benefits:
- Bigger foliage
  → more CO_2-uptake

Foliage costs



Water transport benefits
- Bigger roots
  → more root water uptake
- Bigger vegetated area
  → more CO_2-uptake

Water transport costs

Root benefits
- More roots
  → more water uptake

Root respiration

+ photosynthesis

- foliage costs
- water transport costs
- root respiration

-------------------------------- +

Net carbon profit

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MODEL COMPARISON

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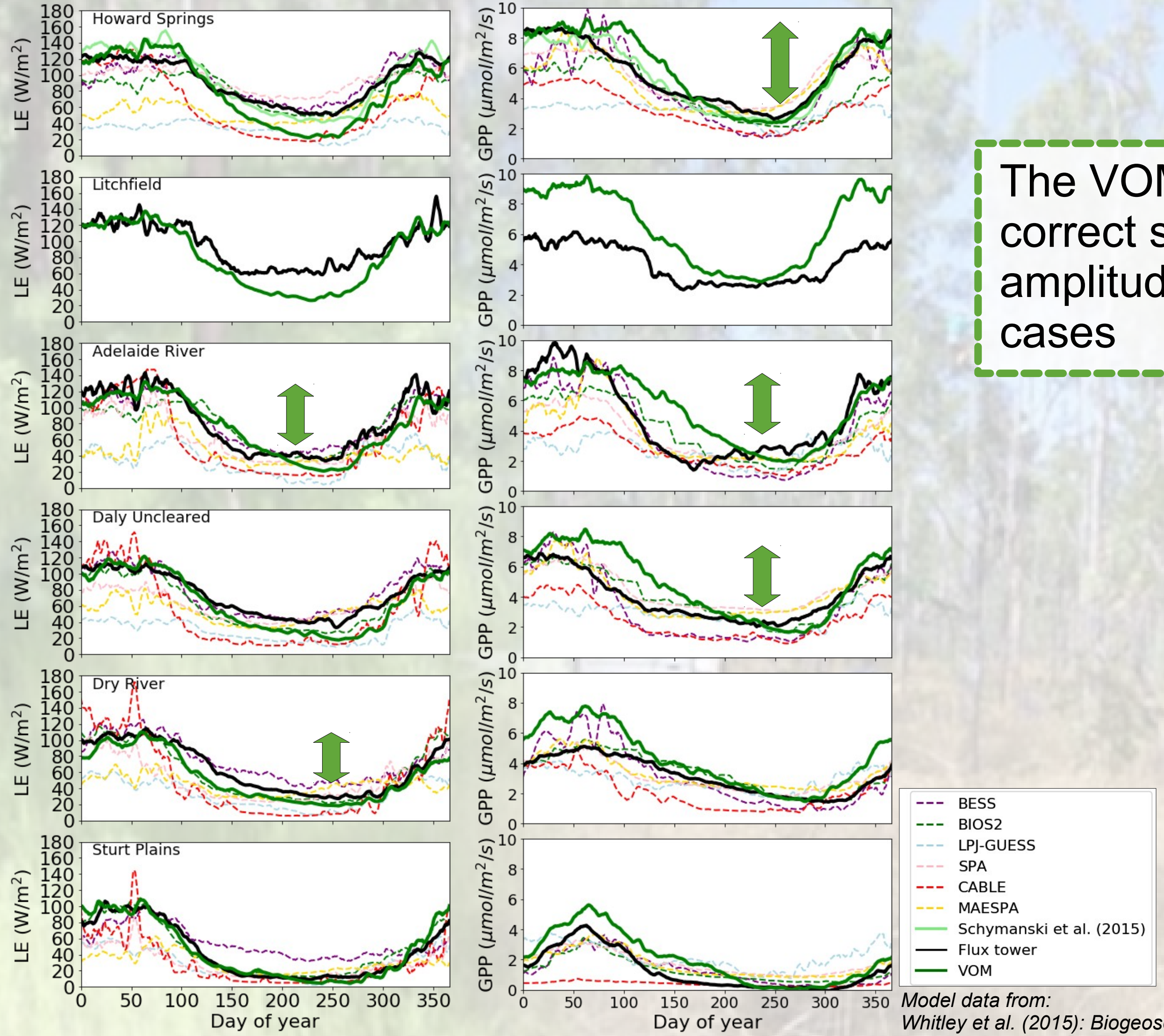
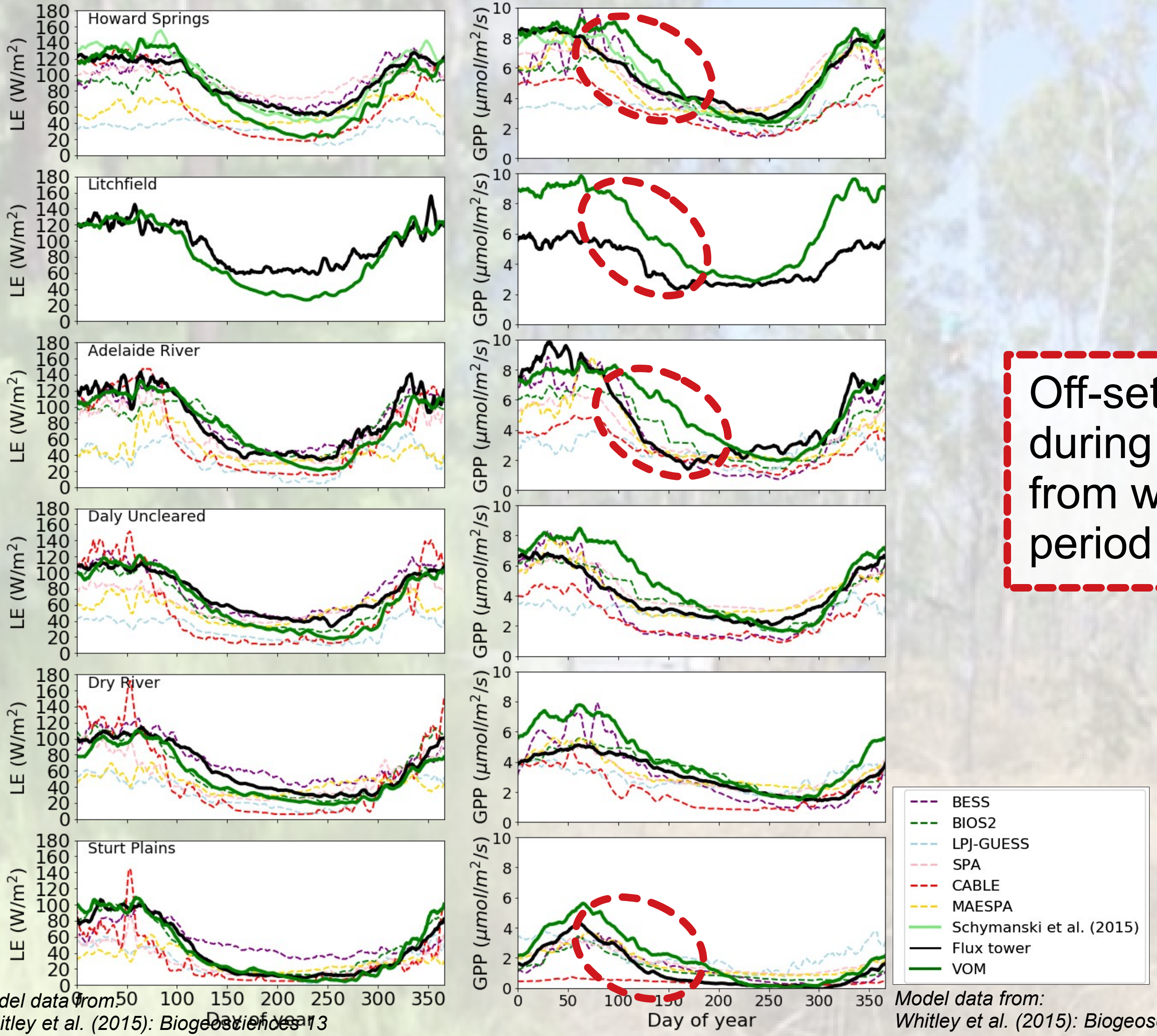


Model data from:
Whitley et al. (2015): Biogeosciences 13

The VOM has a correct seasonal amplitude in most cases

Background

MODEL COMPARISON



Model data from:
Whitley et al. (2015): Biogeosciences 13

Off-set assimilation during transition from wet to dry period

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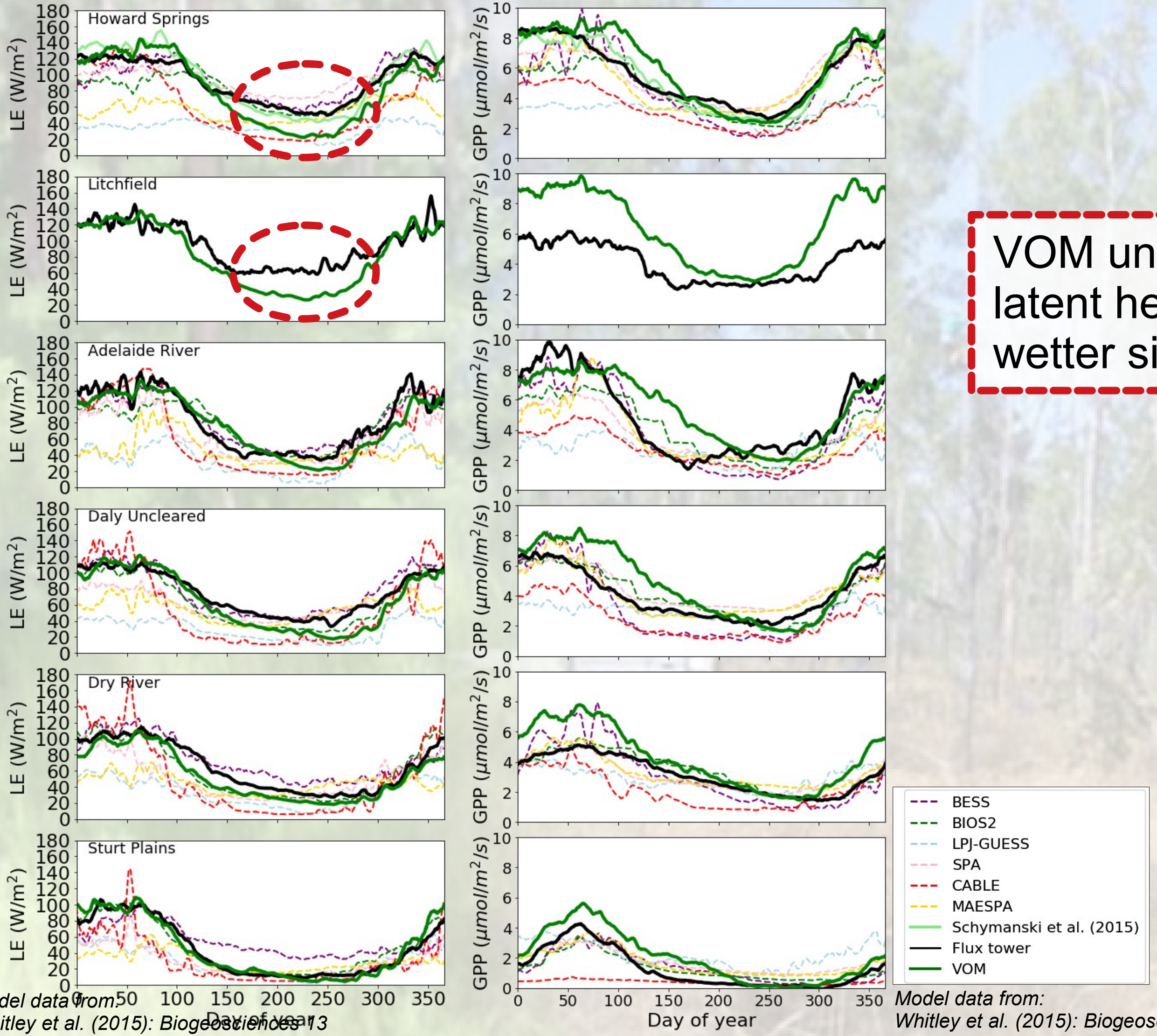

Model data from:
Whitley et al. (2015): Biogeosciences 13

VOM underestimates latent heat for the wetter sites

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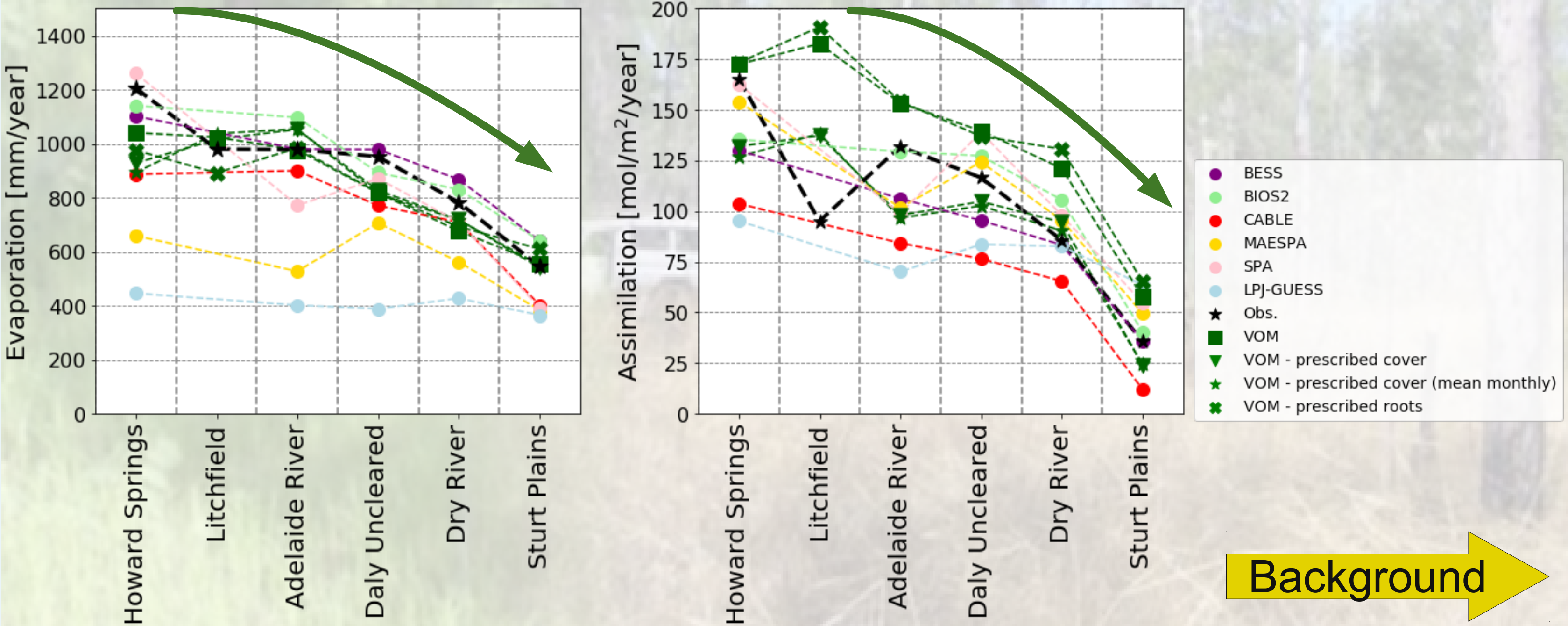
MODEL COMPARISON

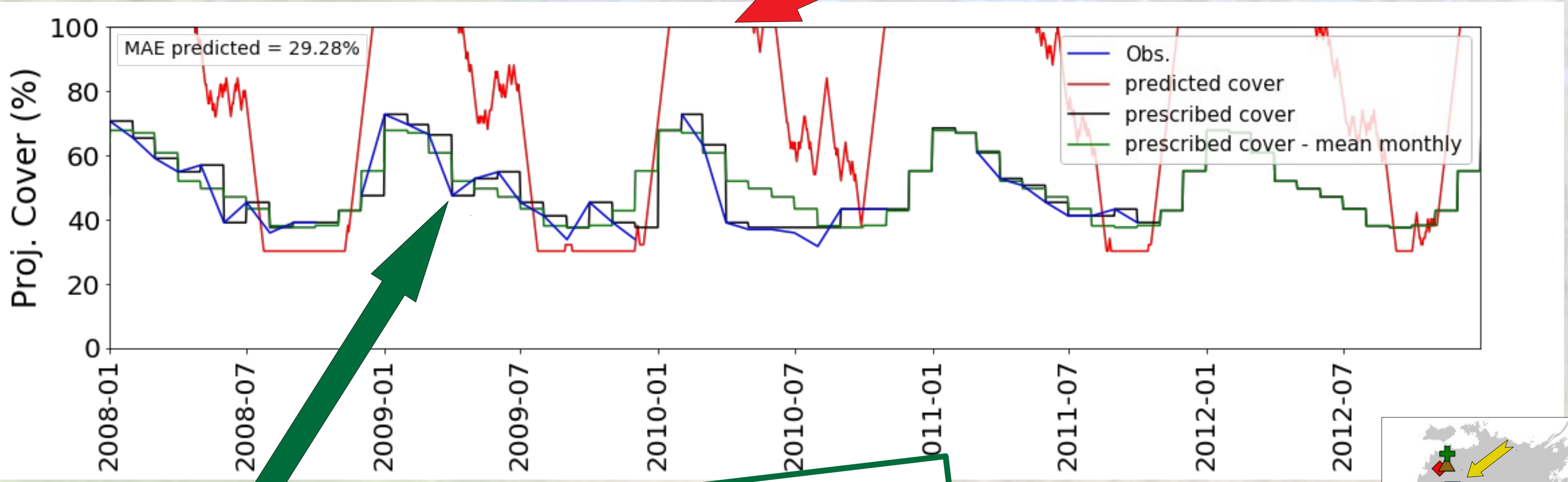
- VOM shows spatial pattern similar or better than other models
- Absence of spatial pattern for several other models
- VOM over-estimates assimilation
- Prescribing cover reduces over-estimation assimilation. More...
- Evaporation at wetter sites under-estimated after prescribing roots. More...



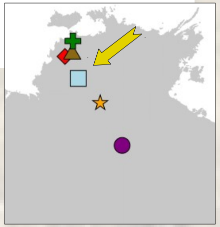
FOLIAGE COSTS

- Temporal signal largely reproduced
- Model always reaches full cover

100% vegetation cover?



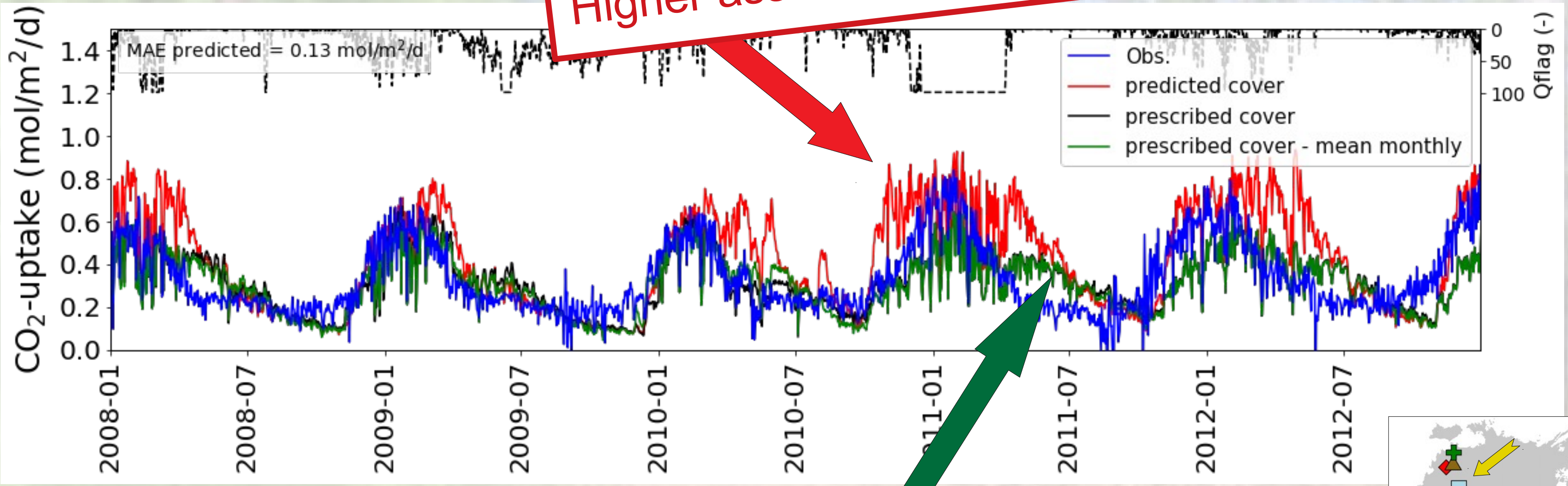
Constructed time series of vegetation cover to prescribe in the VOM



FOLIAGE COSTS

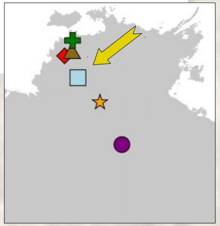
Prescribing vegetation cover:

- Assimilation generally lower. See also the model comparison.



Higher assimilation

Lower assimilation rates when projective cover is prescribed.



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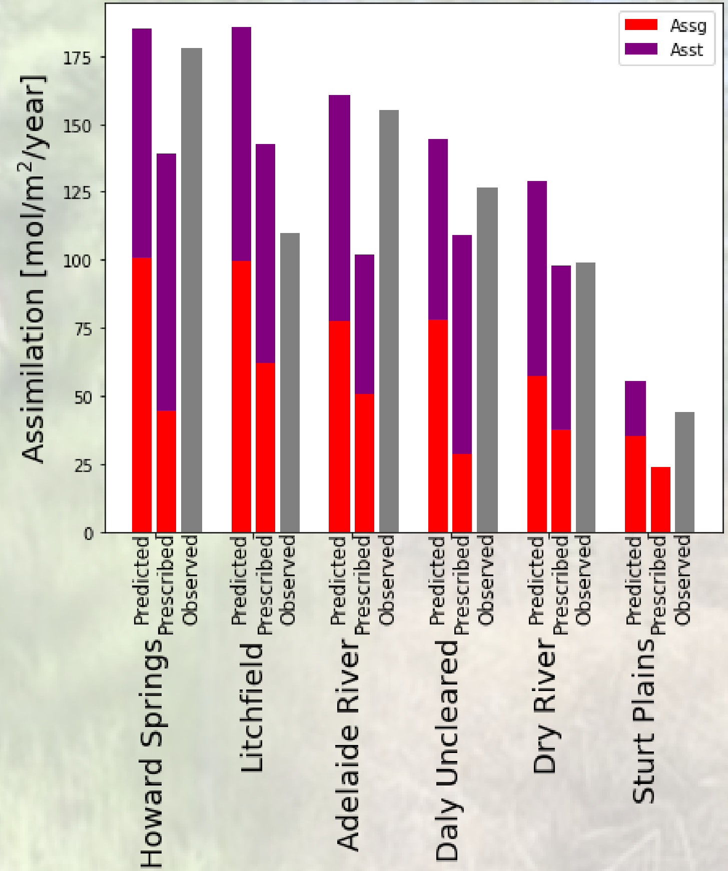
FOLIAGE COSTS

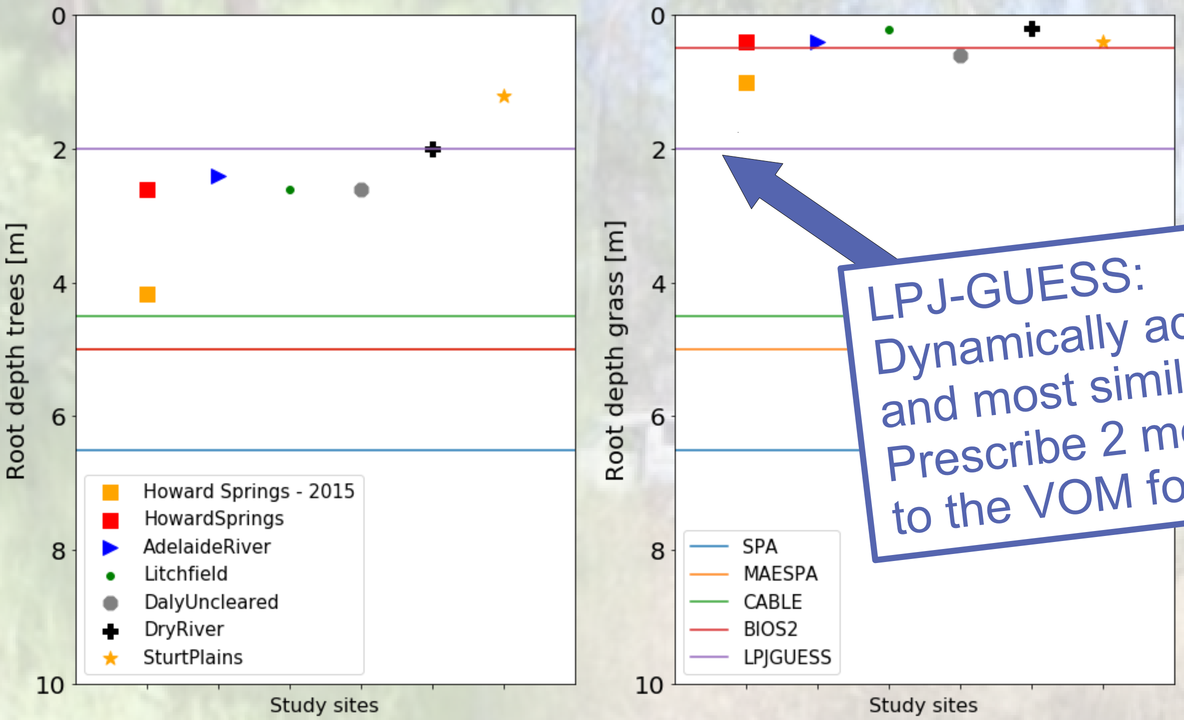
Prescribing vegetation cover:

- Assimilation lower, but not always closer to observations



ROOTING DEPTHS

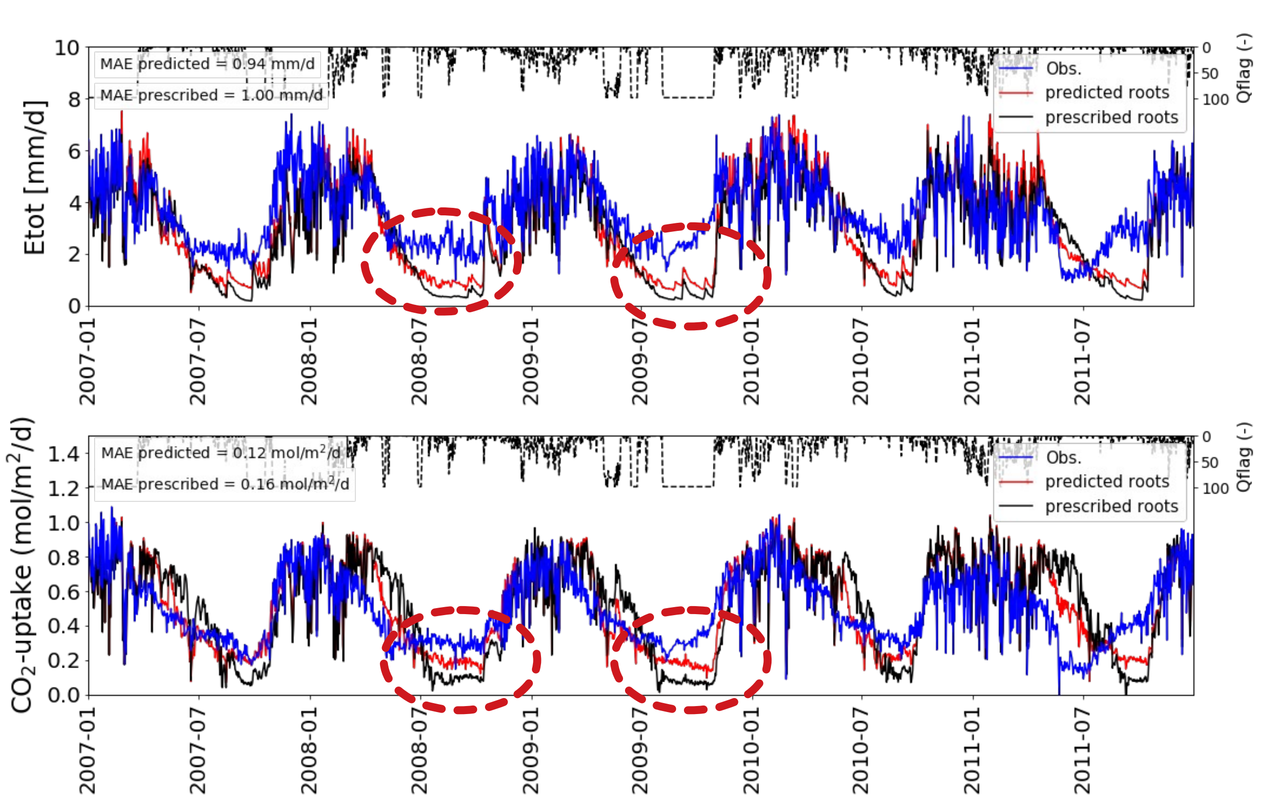
- Large differences between other models and VOM-results
- Pattern over the transect



LPJ-GUESS:
Dynamically adapts vegetation and most similar to the VOM → Prescribe 2 meter rooting depths to the VOM for comparison

ROOTING DEPTHS

- Prescribing roots worsens the under-estimation of E and A in the dry season. See also the model comparison.



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WATER TRANSPORT COSTS

- Fluxes are sensitive to variations in the water transport costs
- Differences occur especially during the dry season

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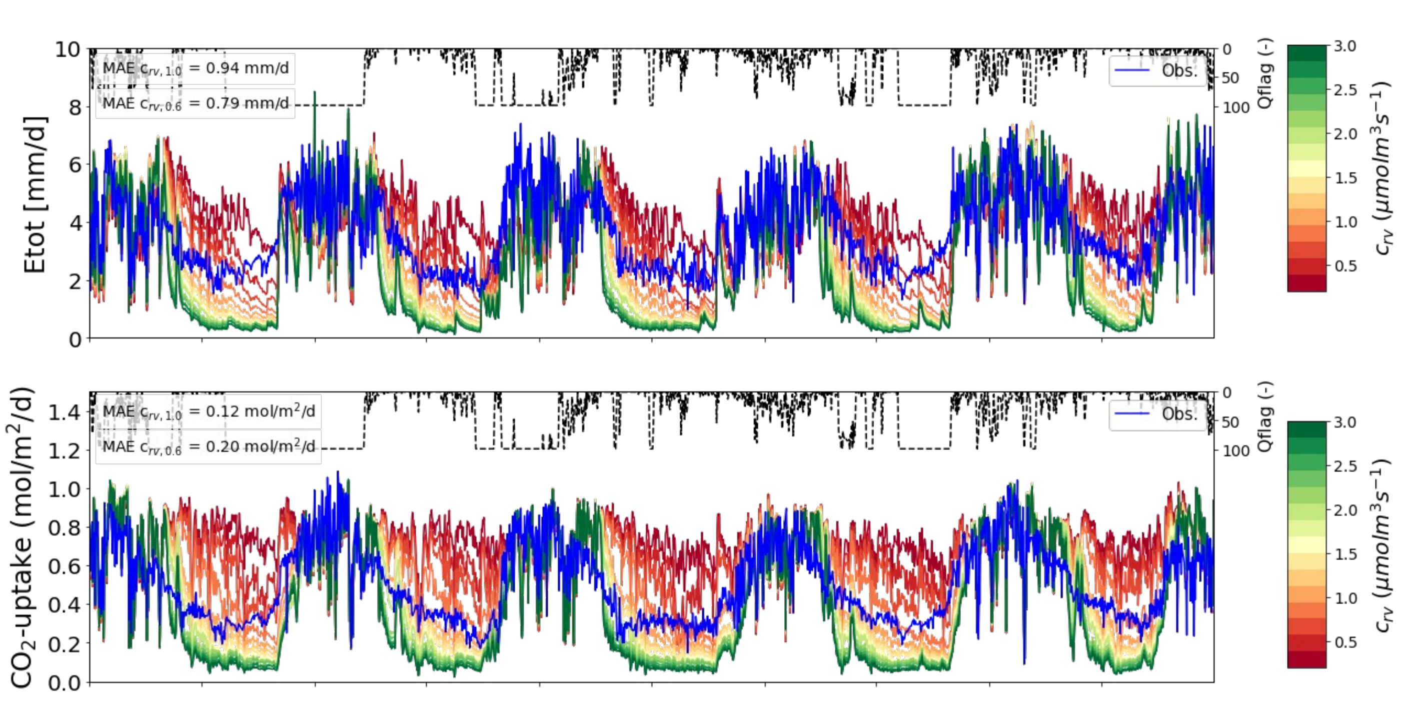

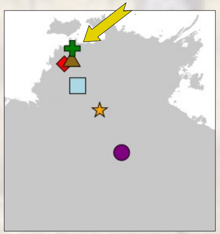

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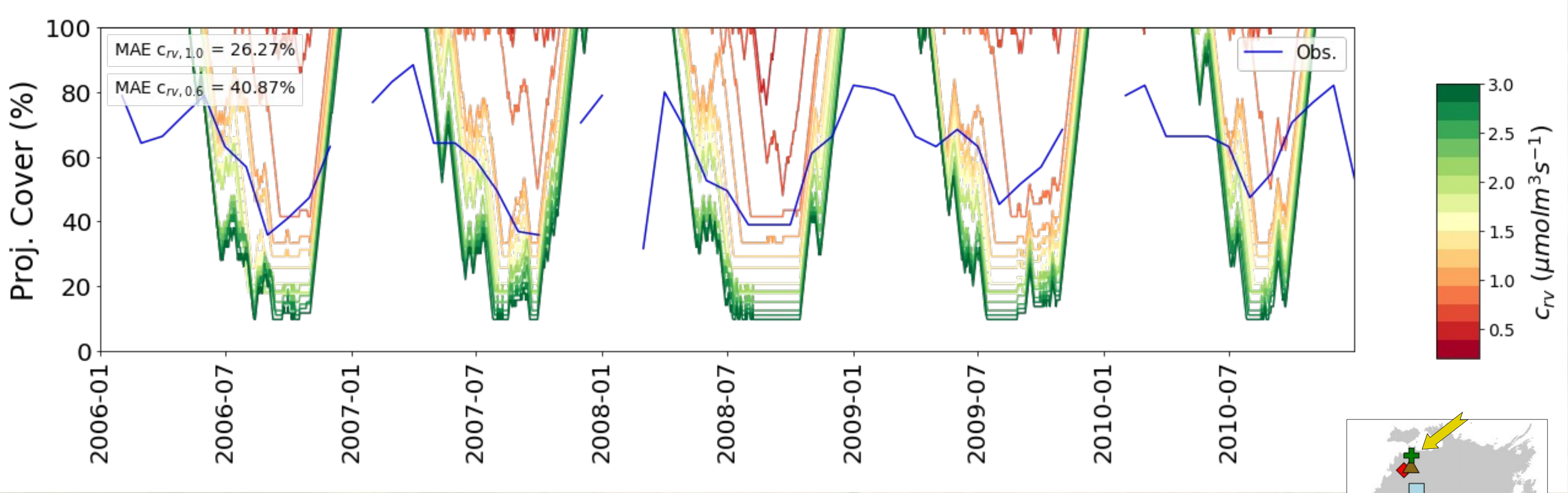
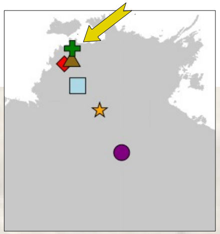
WATER TRANSPORT COSTS

- Vegetative cover during the dry season sensitive to cost factor

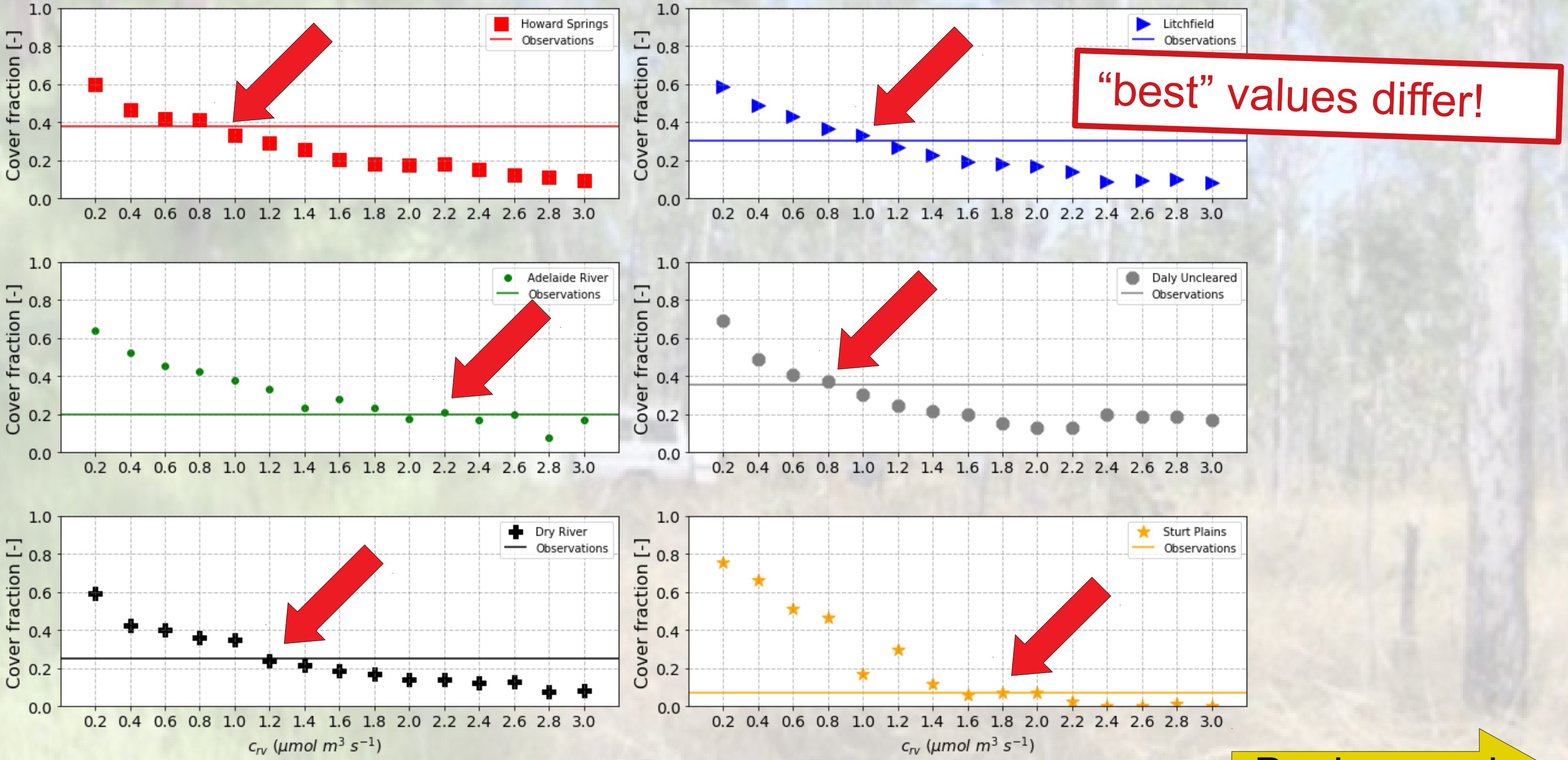




Background

WATER TRANSPORT COSTS

- Remotely sensed vegetation cover during the dry season only reproduced with different cost factors per site.



CONCLUSIONS

- The VOM captured the temporal and spatial variation of carbon and water fluxes similar or better compared to the conventional models.
- Optimality-based vegetation cover has a consistent bias during the wet-season reaching full cover. Traditional prescibed vegetation covers lead to lower CO2-assimilation.
- Optimality-based rooting depths result in a better reproduction of carbon and water fluxes during the dry season.
- Re-calibration of water transport costs for each site resulted in a large variation of the cost parameter for these costs.

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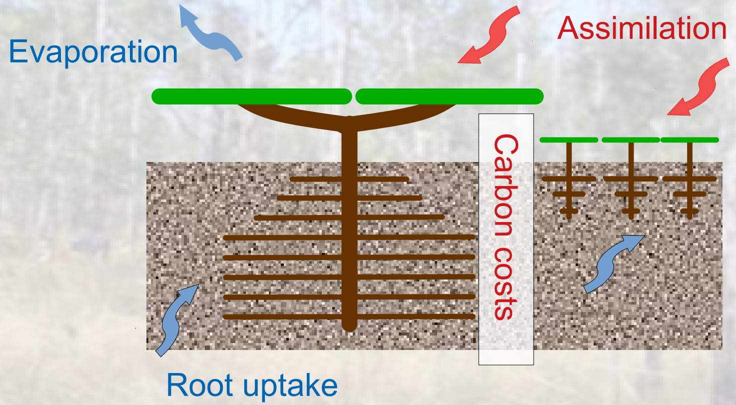
APPENDIX



MODEL COMPARISON

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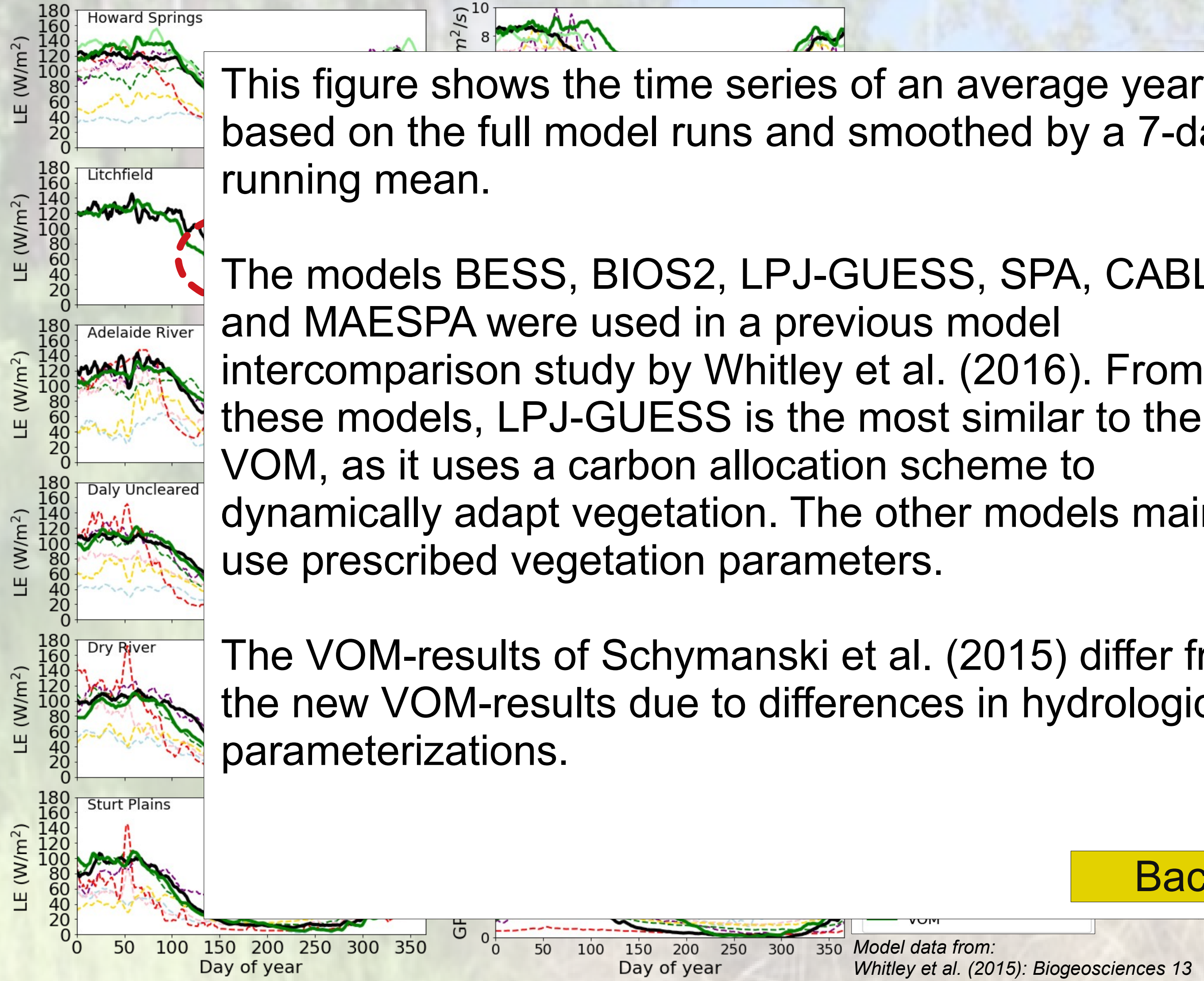

Model data from:
Whitley et al. (2015): Biogeosciences 13

This figure shows the time series of an average year, based on the full model runs and smoothed by a 7-day running mean.

The models BESS, BIOS2, LPJ-GUESS, SPA, CABLE and MAESPA were used in a previous model intercomparison study by Whitley et al. (2016). From these models, LPJ-GUESS is the most similar to the VOM, as it uses a carbon allocation scheme to dynamically adapt vegetation. The other models mainly use prescribed vegetation parameters.

The VOM-results of Schymanski et al. (2015) differ from the new VOM-results due to differences in hydrological parameterizations.

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MODEL COMPARISON

- VOM shows spatial pattern similar or better than other models
- Absence of spatial pattern for several other models
- VOM over-estimates assimilation
- Prescribing cove
- Evaporation wett
roots. More...

This figure shows the mean annual fluxes of evaporation and assimilation for the models and observations from the flux towers. The sites are ordened from the wettest site on the left (Howard Springs) to the driest on the right (Sturt Plains).

The VOM shows a clear pattern of decreasing values of evaporation and assimilation. Some models show this too, but MAESPA and LPJ-GUESS do not show a pattern over the transect. At the same time, LPJ-GUESS is actually the most similar to the VOM as it dynamically models vegetation.

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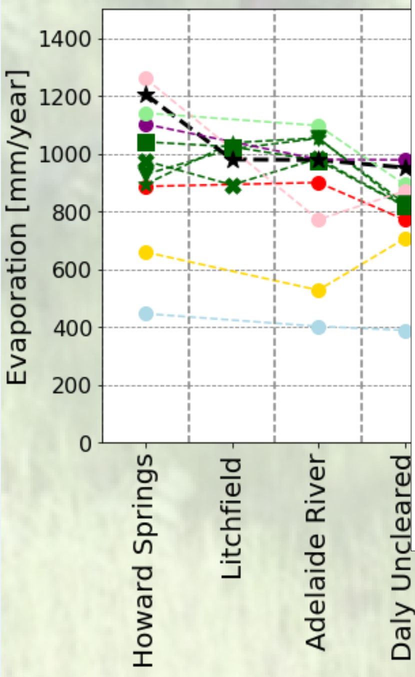
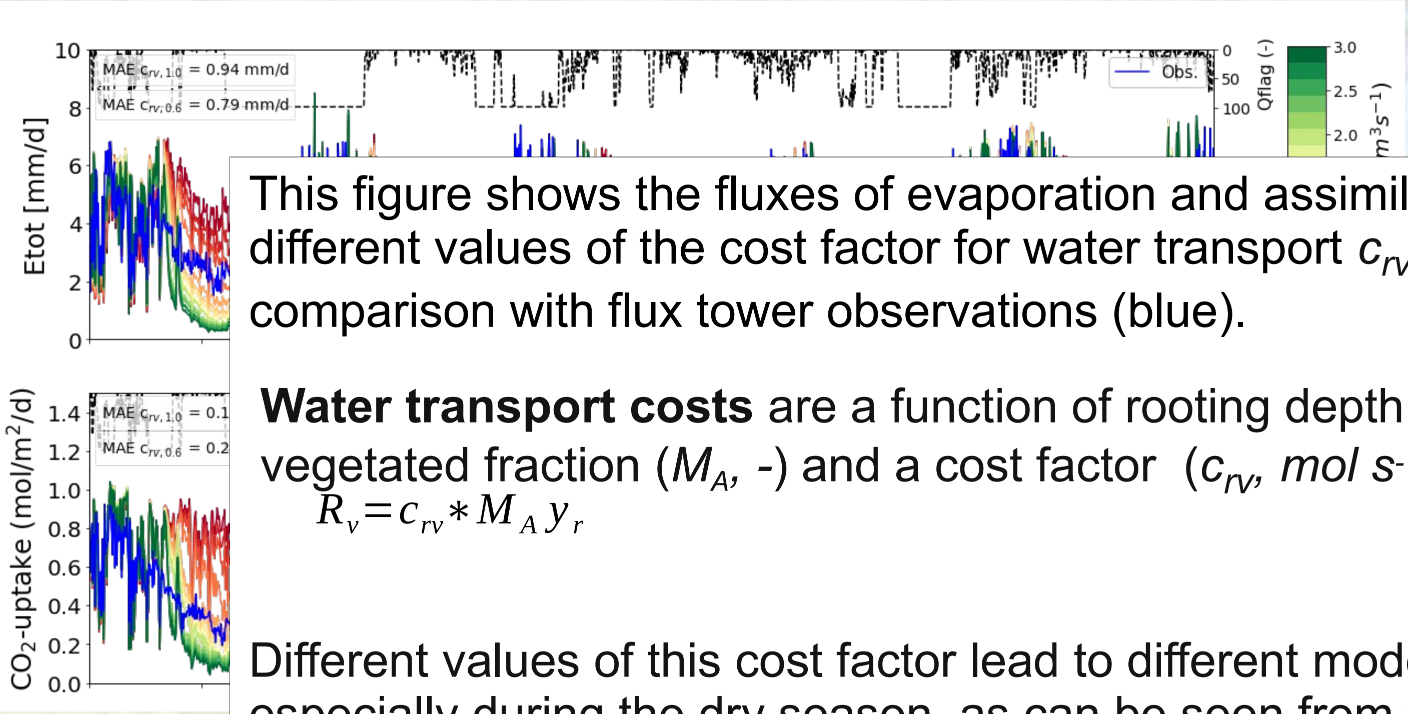


WATER TRANSPORT COSTS

- Fluxes are sensitive to variations in the water transport costs
- Differences occur especially during the dry season



This figure shows the fluxes of evaporation and assimilation for different values of the cost factor for water transport c_{rv} in comparison with flux tower observations (blue).

Water transport costs are a function of rooting depth (y_r), vegetated fraction (M_A, -) and a cost factor (c_{rv}, *mol s*$^{-1}$ *m*$^{-3}$):

$$R_v = c_{rv} * M_A \, y_r$$

Different values of this cost factor lead to different model fluxes especially during the dry season, as can be seen from this figure.

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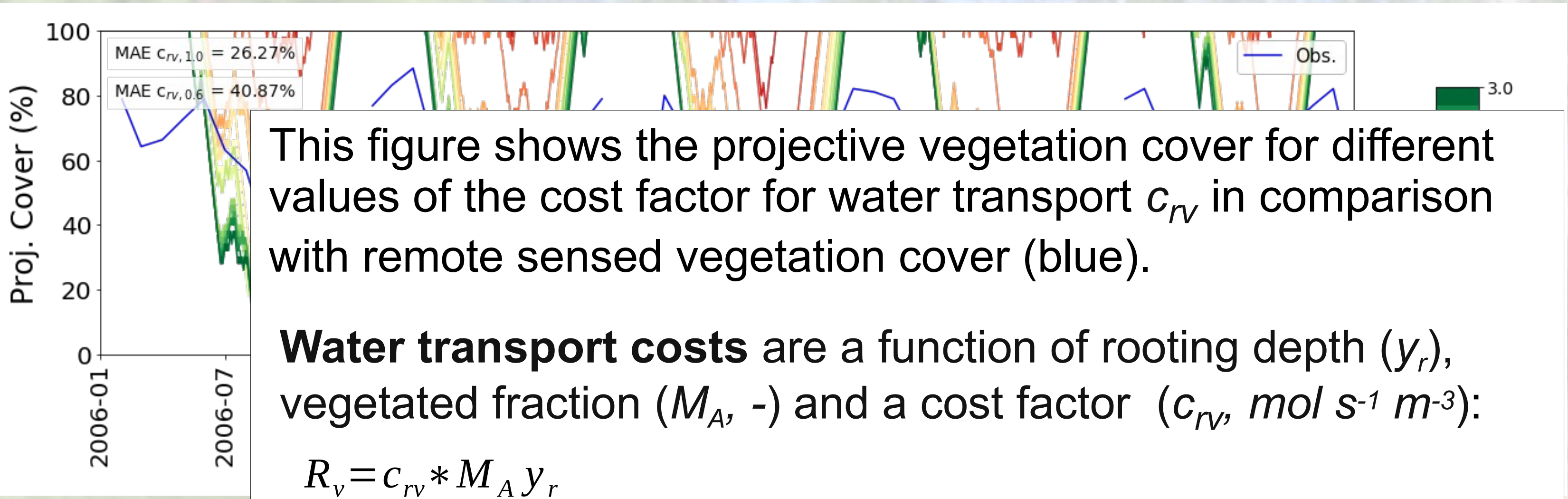
WATER TRANSPORT COSTS

- Vegetative cover during the dry season sensitive to cost factor



This figure shows the projective vegetation cover for different values of the cost factor for water transport c_{rv} in comparison with remote sensed vegetation cover (blue).

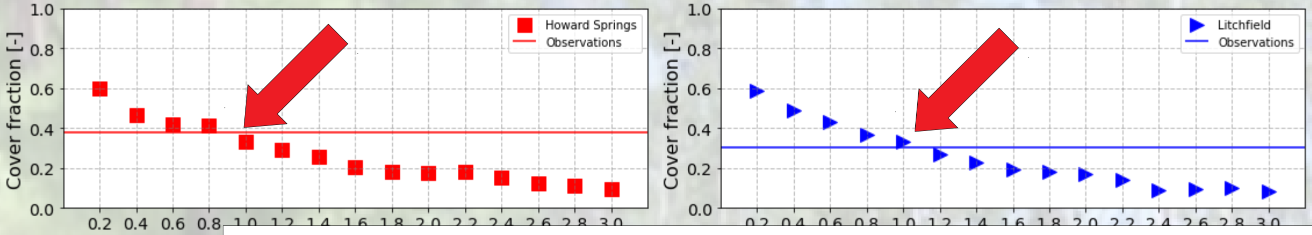
Water transport costs are a function of rooting depth (y_r), vegetated fraction (M_A, -) and a cost factor (c_{rv}, $mol\ s^{-1}\ m^{-3}$):

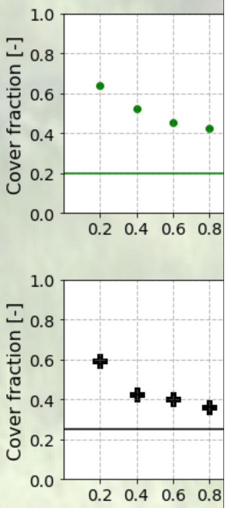
$$R_v = c_{rv} * M_A y_r$$

Different values of this cost factor lead especially during the dry season to differences in the vegetative cover, as can be seen from this figure.

WATER TRANSPORT COSTS

- Remotely sensed vegetation cover during the dry season only reproduced with different cost factors per site.



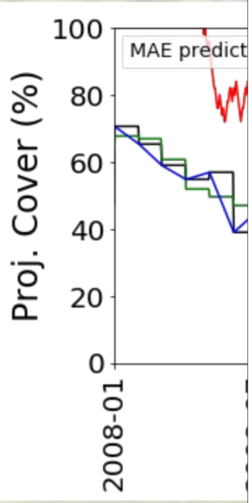


This figure shows the mean vegetation cover during the dry season (May-Sept.) for vegetation cover derived from fPar (Donohue et al. 2016) and the results of the VOM for different values of the cost factor for water transport.

It can be noted here that each site needs a different value of this cost factor in order to reproduce the remotely sensed vegetation cover. It could be argued that this cost factor is not constant over the transect and is a function of other climatic characteristics.

FOLIAGE

- Temporal
- Model alw



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This figure shows the mean vegetation cover predicted by the VOM (red) and derived from remotely sensed fPar-data (blue). It can be noted that the VOM always reaches 100% full cover during the wet season, which is not realistic. This happened consistently for all six study sites along the NATT.

Time series of vegetation cover were constructed based on the remotely sensed vegetation cover in order to prescribe to the VOM. This was done in order to assess whether improvements in projective cover would also reduce over-estimations in the especially CO2-assimilation.

The time series were constructed in two ways:

1. The mean monthly values of vegetation cover were repeated for all years, which is a common approach in land surface modelling.
2. The actual values of remotely sensed vegetation cover were used, but extended with the mean monthly values to cover the full model period.

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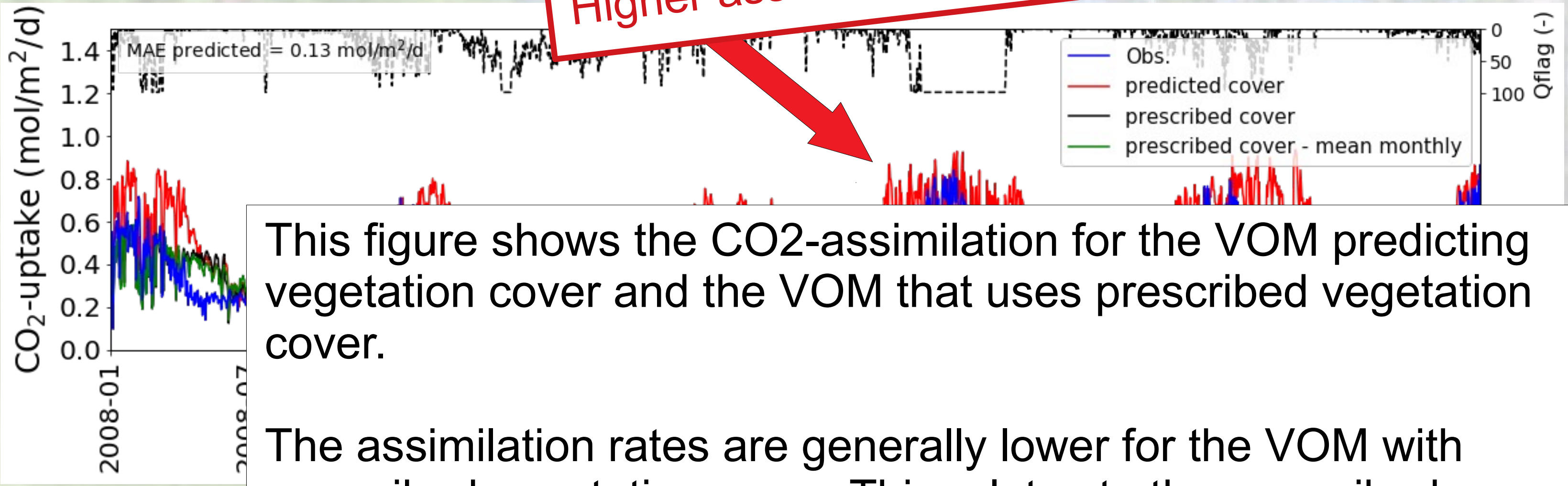
FOLIAGE COSTS

Prescribing vegetation cover:

- Assimilation generally lower. See also the model comparison.

Higher assimilation



This figure shows the CO2-assimilation for the VOM predicting vegetation cover and the VOM that uses prescribed vegetation cover.

The assimilation rates are generally lower for the VOM with prescribed vegetation cover. This relates to the prescribed vegetation cover being generally lower compared to the predicted vegetation cover.

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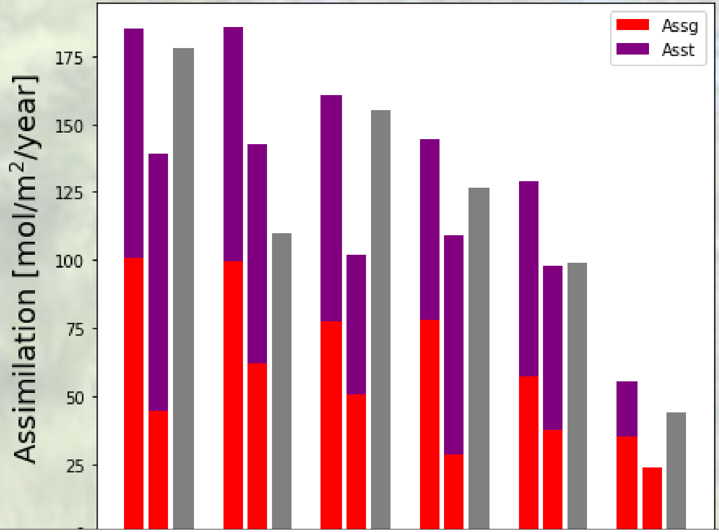
FOLIAGE COSTS

Prescribing vegetation cover:

- Assimilation lower, but not always closer to observations



The mean annual values of CO2-assimilation show also that prescribing vegetation cover leads to lower assimilation rates. However, it is not directly clear whether prescribed or predicted vegetation cover leads to mean annual fluxes closer to the observations.

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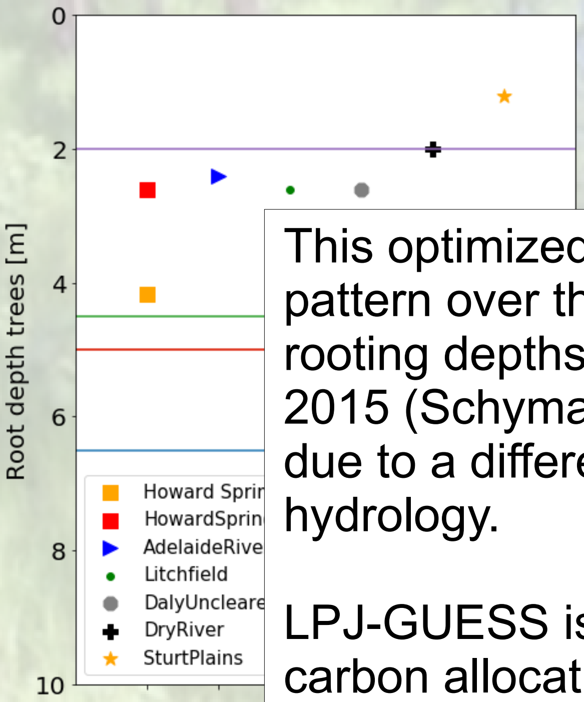
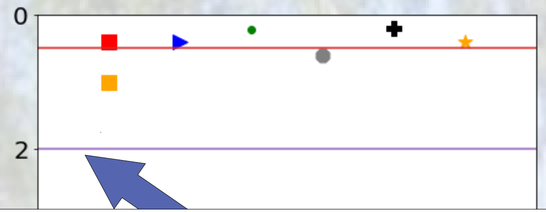
ROOTING DEPTHS

- Large differences between other models and VOM-results
- Pattern over the transect





This optimized rooting depths for trees and grasses show a pattern over the transect. In comparison with other models, the rooting depths also remain rather shallow. The VOM results of 2015 (Schymanski et al. 2015) predict different rooting depths due to a different schematization and parameterization of the hydrology.

LPJ-GUESS is the most similar to the VOM, as it uses a carbon allocation scheme to dynamically model vegetation. Therefore, the rooting depths of LPJ-GUESS were used to prescribe to the VOM for comparison.

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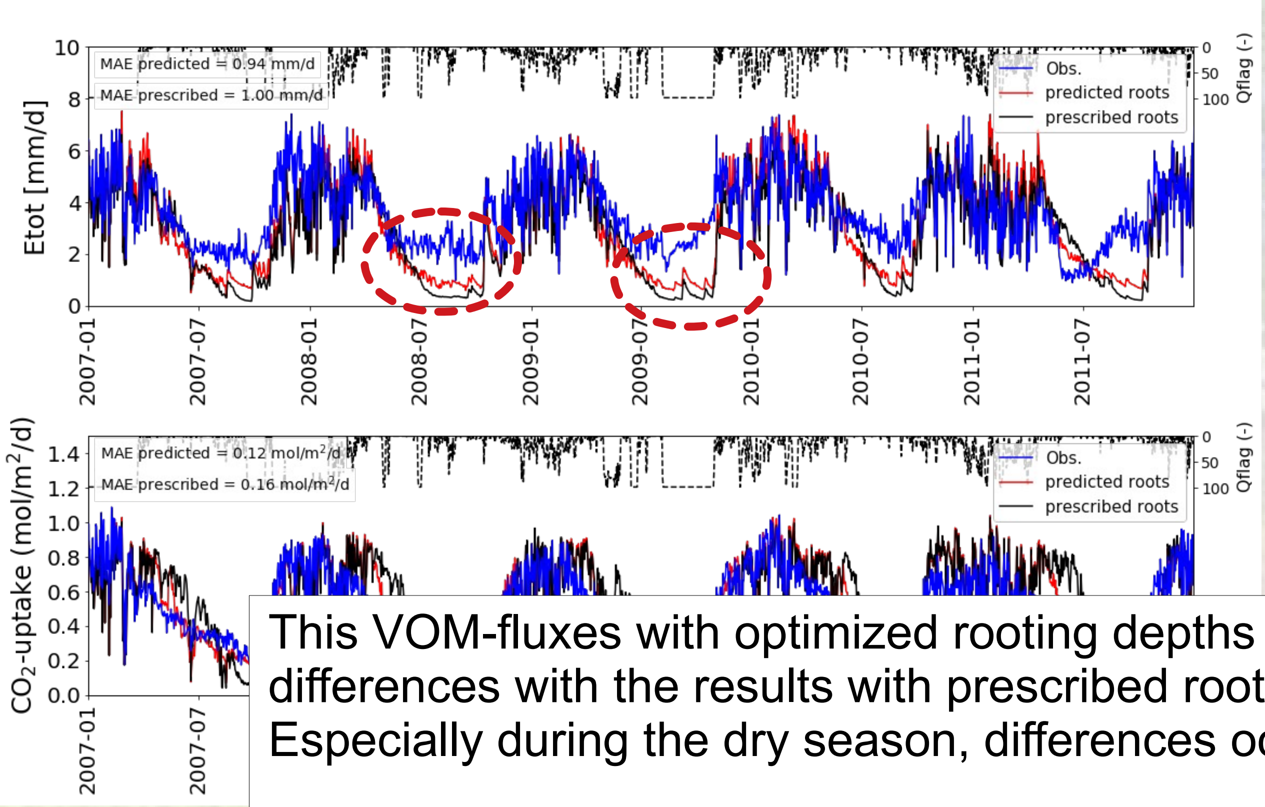
ROOTING DEPTHS

- Prescribing roots worsens the under-estimation of E and A in the dry season. See also the model comparison.



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This VOM-fluxes with optimized rooting depths show strong differences with the results with prescribed rooting depths. Especially during the dry season, differences occur.

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