# The impact of highly-transpiring angiosperms on Cretaceous climate : a modelling approach with the IPSL atmosphere-land surface model


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## Context

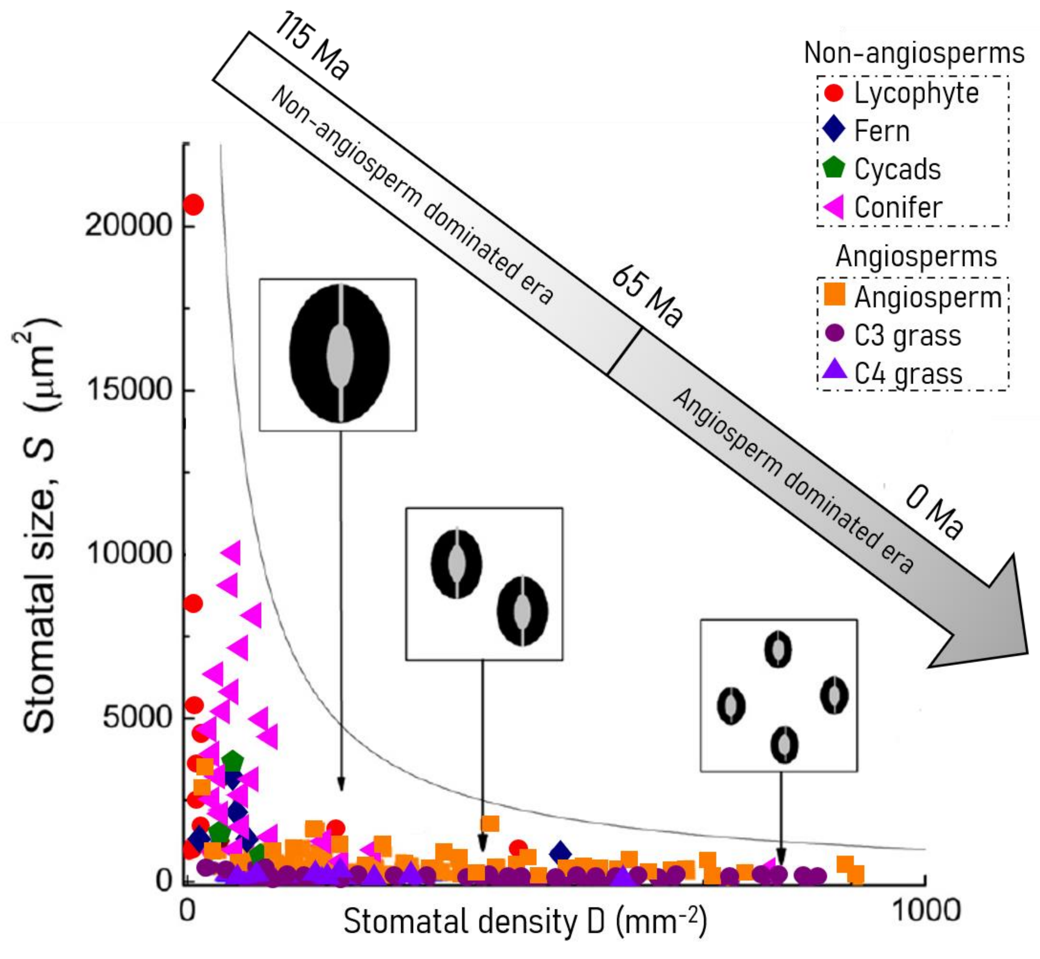


Fig 1 : Stomatal size versus stomatal density for different extant plants. Adapted from [1]

Evidence of leaf structural evolution with the Cretaceous radiation of angiosperms, estimated by maximum geometric stomatal conductance to $H_2O$ [2]:

$$g_{max} = \frac{dDa_{max}}{v\left(l + \frac{\pi}{2}\sqrt{\frac{a_{max}}{\pi}}\right)}$$

$g_{max}$ : maximum geometric stomatal conductance to $H_2O$ (mol/m²/s)
$d$ : diffusivity of water in air (m²/s)
$D$ : stomatal density (number/m²)
$a_{max}$ : maximum stomatal pore area (m²)
$v$ : molar volume of air (m³/mol)
$l$ : depth of the stomatal pore (m)

When using this equation, the maximum geometric stomatal conductance to $H_2O$ is smaller by **40 %** for non-angiosperms compared to modern angiosperms

## Question

How does higher angiosperm stomatal conductance to $H_2O$ impact transpiration and precipitations over the Cretaceous ?

## Method

ORCHIDEE model code [3] adaptation developed to represent as closely as possible $g_{max}$ :

$$g_{max}' = g_0 + \frac{A}{C_i} * fvpd * r$$

$g_{max}'$ : stomatal conductance to $H_2O$ (mol/m²/s) per leaf at top of canopy
$g_0$ : residual stomatal conductance to $CO_2$ (mol/m²/s)
$A$ : net $CO_2$ assimilation rate (mol/m²/s)
$C_i$ : intercellular $CO_2$ partial pressure (bar)
$fvpd$ : factor describing the effect of leaf to air vapor pressure difference on $g_{max}'$ (m³/mol)
r : conversion factor from $CO_2$ to $H_2O$

| Simulations | PI | 0.4xPI | 115Ma | 0.4x115Ma |
|---|---|---|---|---|
| Geography | Modern | Modern | Paleo [4] | Paleo [4] |
| $[CO_2]$a (ppm) | 280 | 280 | 1120 [4] | 1120 [4] |
| Vegetation initialization | Modern | Modern | Paleo [4] | Paleo [4] |
| Angiosperm $g_{max}'$ reduction | - | - 40 % | - | - 40 % |

Table 1 : Simulation setups for preindustrial and paleo control (PI and 115Ma respectively) and without highly-transpiring angiosperms (respectively 0.4xPI and 0.4x115Ma)

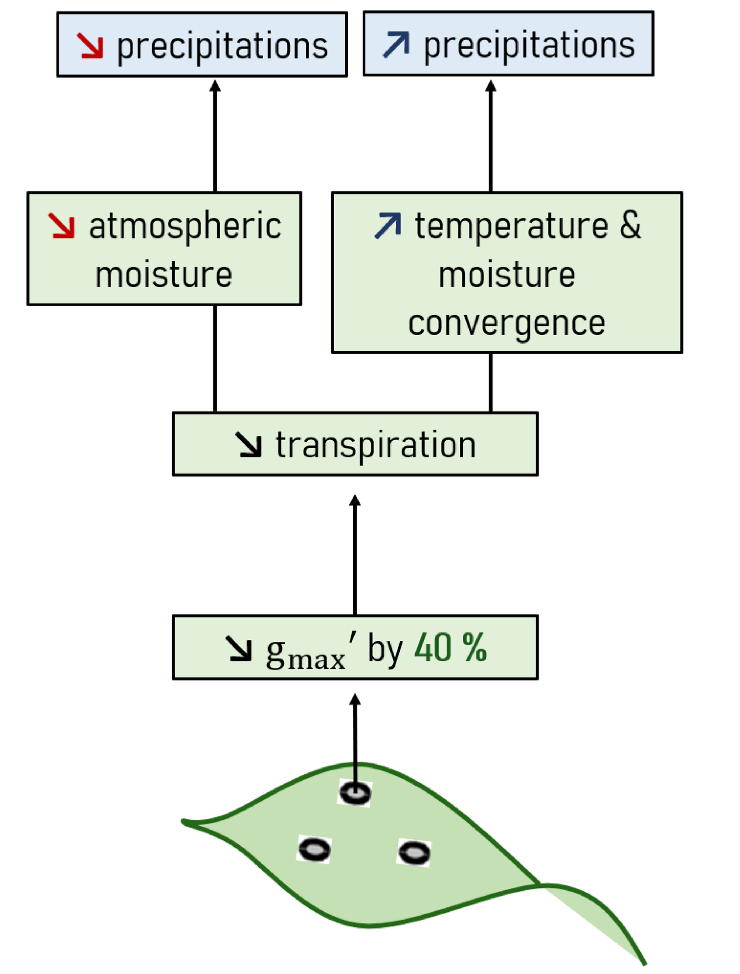


Fig 2 : Competing effects on precipitations when reducing maximum stomatal conductance to $H_2O$

## Results (1)

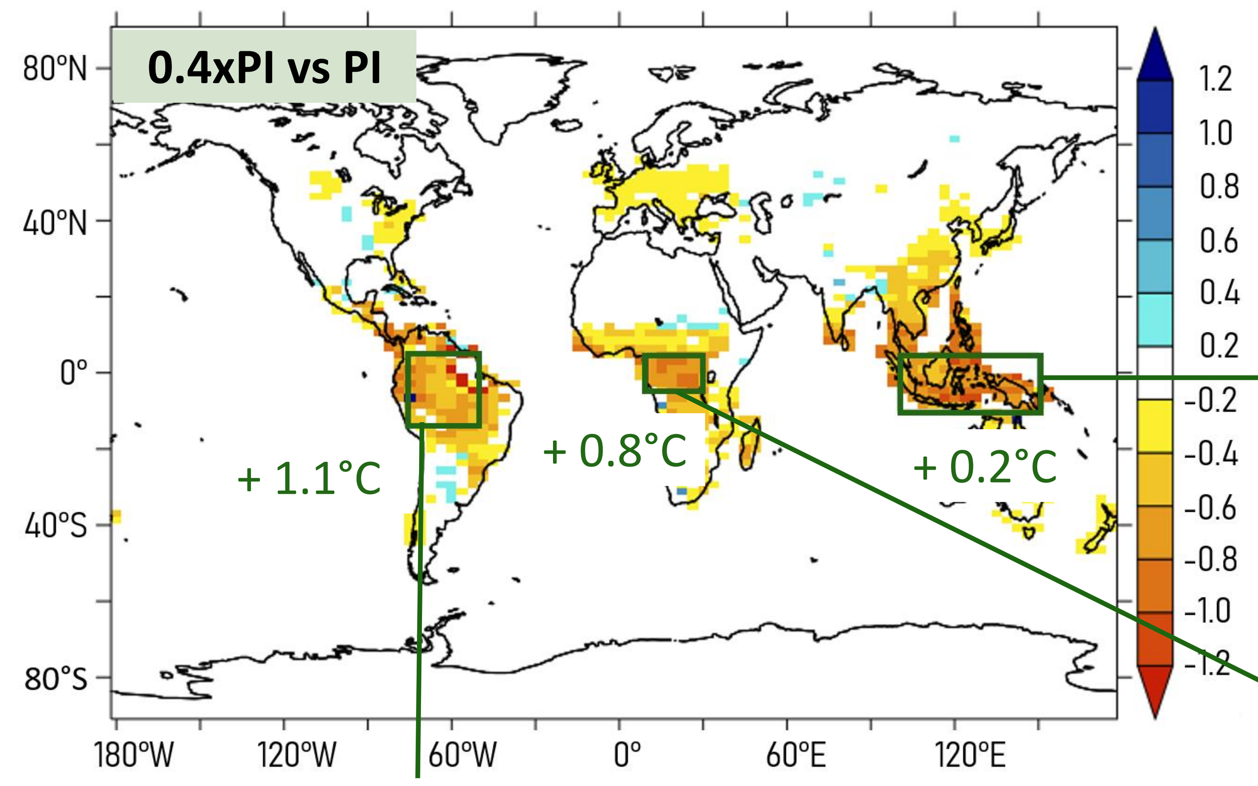


Fig 3 : Anomaly of annual transpiration (mm/d) in shaded colors and anomaly of annual surface temperature (°C) in insets for Amazonia, Congo Basin and Indonesia for 0.4xPI minus PI

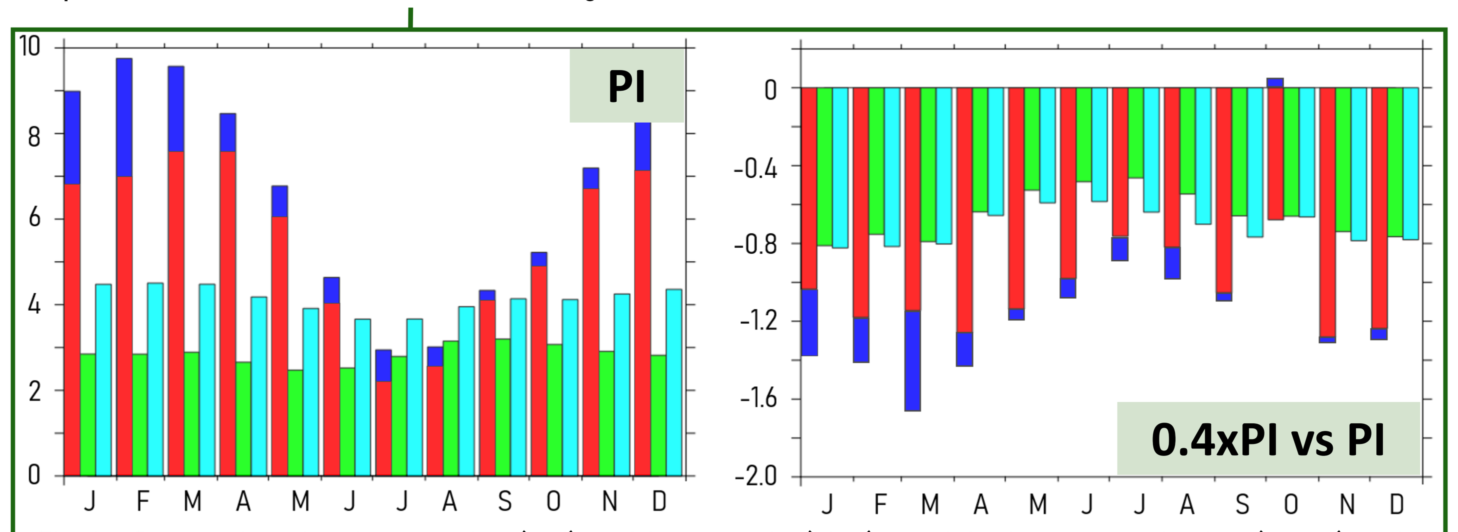


Fig 4 : Seasonal cycle of convective (red) and large scale (blue) precipitations, transpiration (green) and evaporation (light blue) for PI (left) and 0.4xPI minus PI (right) over Amazonia. Values are in mm/d.

Over Amazonia, the main effect is the decrease of convective precipitations associated with that of transpiration and evaporation.

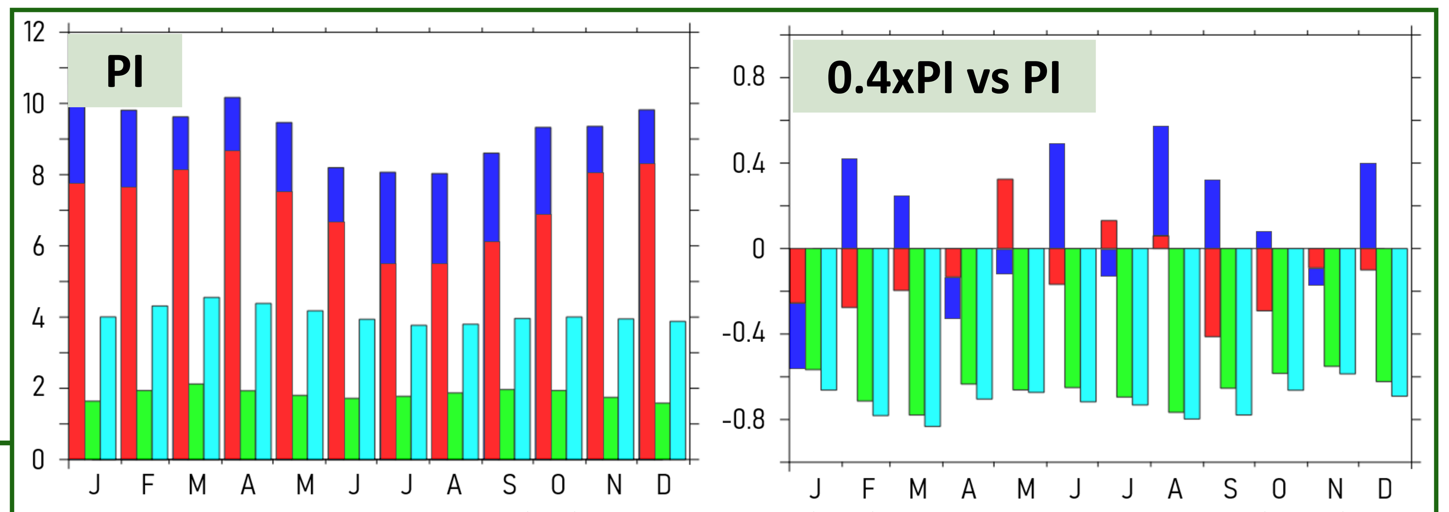


Fig 5 : Seasonal cycle of convective (red) and large scale (blue) precipitations, transpiration (green) and evaporation (light blue) for PI (left) and 0.4xPI minus PI (right) over Indonesia. Values are in mm/d.

Over Indonesia, no clear signal is found on precipitations because of complex precipitation regimes [5].

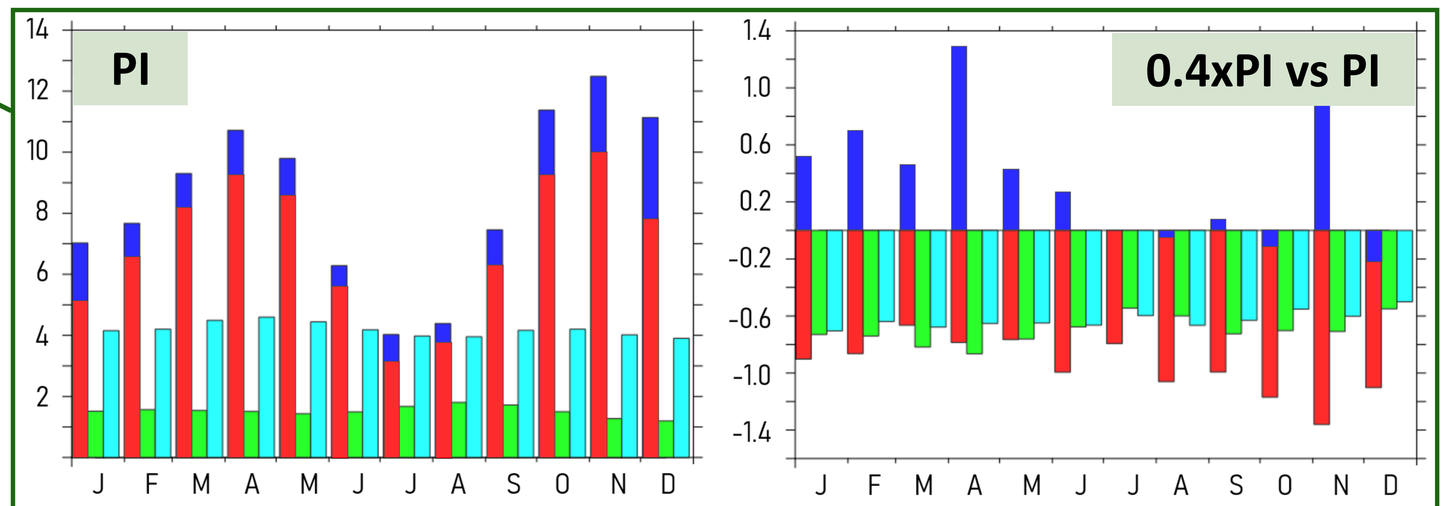


Fig 6 : Seasonal cycle of convective (red) and large scale (blue) precipitations, transpiration (green) and evaporation (light blue) for PI (left) and 0.4xPI minus PI (right) over Congo Basin. Values are in mm/d.

Over the Congo Basin, from July to December, the main effect is the decrease of convective precipitations associated with that of transpiration and evaporation. From January to June, the increase of large scale precipitations with surface temperature offsets the decrease of convective precipitations.

## Results (2)

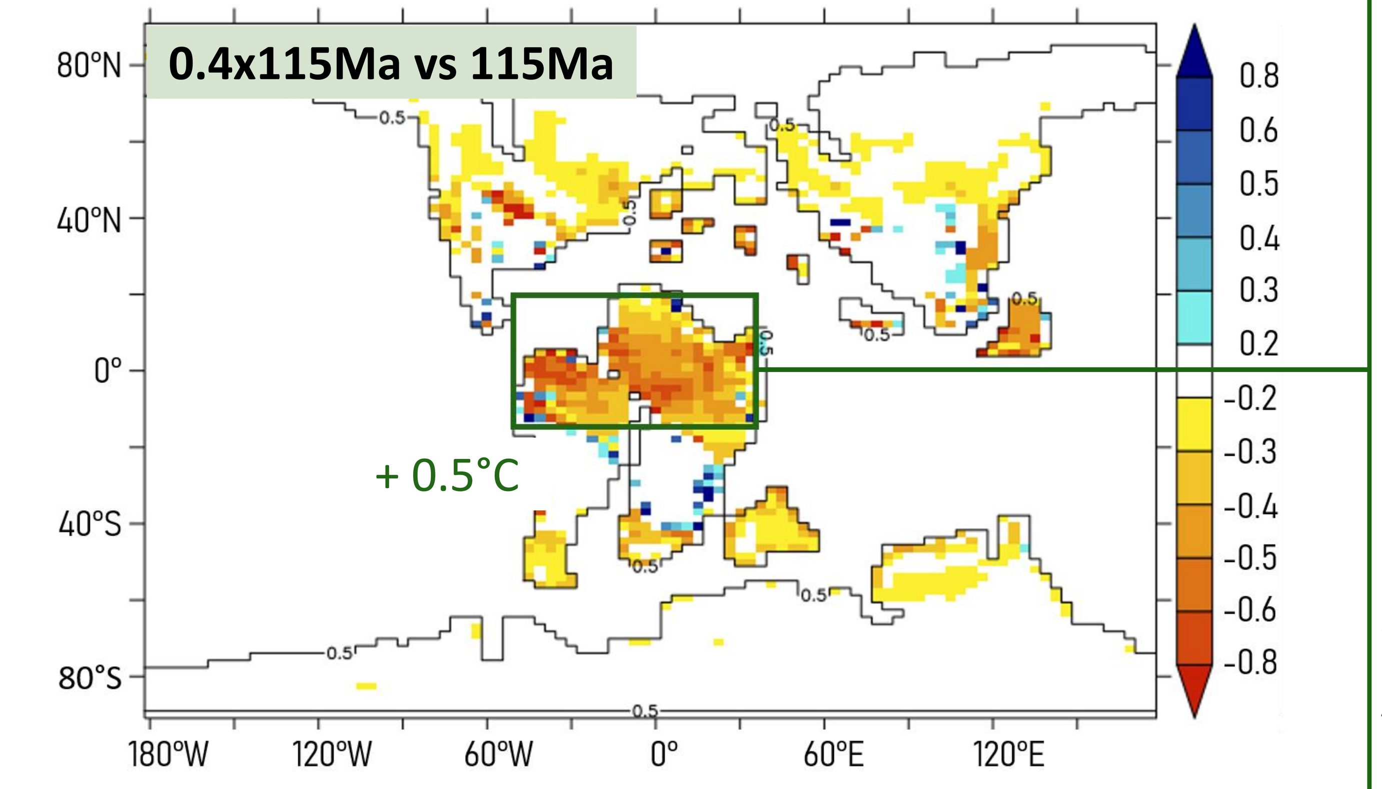


Fig 7 : Anomaly of annual transpiration (mm/d) in shaded colors and paleo tropics anomaly of annual surface temperature (°C) in insets for 0.4x115Ma minus 115Ma

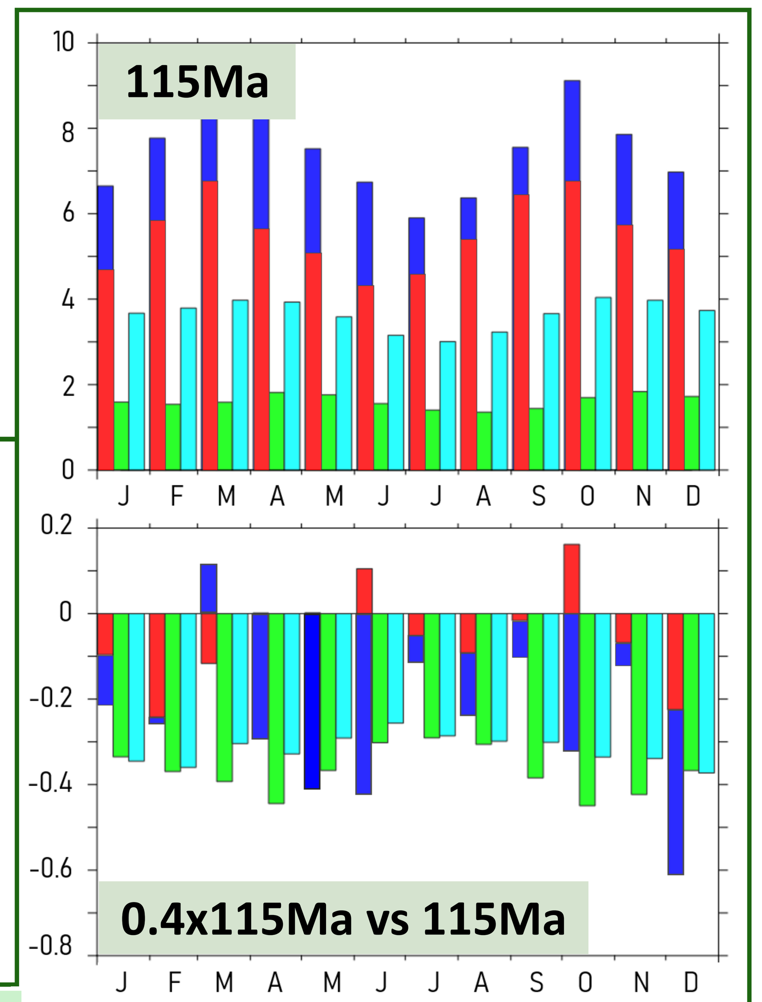


Fig 8 : Seasonal cycle of convective (red) and large scale (blue) precipitations, transpiration (green) and evaporation (light blue) for 115Ma (top) and 0.4x115Ma minus 115Ma (bottom) over the paleo tropics. Values are in mm/d.

Over the paleo tropics, the main effect is the decrease of large scale precipitations compared to that of convective precipitations with transpiration and evaporation decrease.

## Conclusion

The dominant effect of reducing angiosperm stomatal conductance by **40 %** on precipitation patterns is found in the tropics [6] and depends on the regional atmospheric circulation climatology [7].
For Cretaceous simulations, large scale precipitations dominate the negative anomaly of precipitations over the paleo tropics, with no similar response for preindustrial simulations. The precipitation decrease suggests that angiosperms play a role in tropical rainforests establishment [8].


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[1] : Maximum leaf conductance driven by CO2 effects on stomatal size and density over geologic time, Franks et Beerling (2009). PNAS
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[5] : Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. Aldrian et Dwi Susanto (2003). International. Journal of Climatology
[6] : Vegetation-climate interactions in the warm mid-Cretaceous. Zhou et al. (2012). Clim. Past
[7] : Surface warming and atmospheric circulation dominate rainfall changes over tropical rainforests under global warming. Saint-Lu et al. (2019). Geophysical Research Letters
[8] : Angiosperms helped put the rain in the rainforests. Boyce et al. (2010). Annals of the Missouri Botanic Garden