Land Components Control the ENSO Representation in the Earth System Model MIROC-ES2L

Keiichi Hashimoto[1,2], Tomohiro Hajima[2], Hiroaki Tatebe[2], Takahito Kataoka[2], and Hiroaki Miura[1]
(khashimoto@eps.s.u-tokyo.ac.jp)
1 Graduate School of Science , The University of Tokyo, Tokyo, Japan
2 Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

This presentation participates in OSPP
Outstanding Student & PhD candidate Presentation contest
EGU25-4636

Abstract

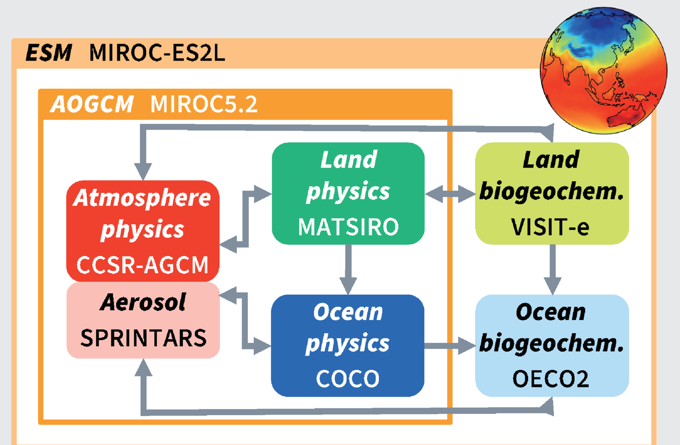
Terrestrial vegetation affects the atmosphere through both biogeochemical and physical processes. Radiative forcing is affected by carbon uptake and release, while albedo, evapotranspiration, and surface roughness also depend on vegetation. In Earth system models (ESMs), vegetation growth is often represented by prognostic simulations of the leaf area index (LAI). MIROC-ES2L, an ESM version of the MIROC climate model, simulates a larger El Niño-Southern Oscillation (ENSO) amplitude compared to simulations that prescribe observed LAI.

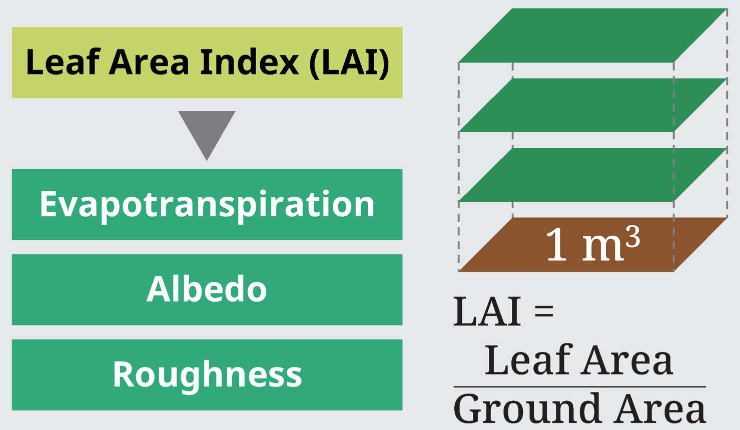
To investigate the cause of this enhanced ENSO amplitude in MIROC-ES2L, we compared the feedback processes contributing to El Niño growth in two experiments: one with observed LAI and the other with model-prognosed LAI. The prognosed LAI experiment showed stronger zonal advection, Ekman, and meridional advection feedbacks, associated with warmer sea surface temperatures (SSTs) in the eastern equatorial Pacific.

Sensitivity experiments were conducted to identify the regions where LAI contributes most significantly to SST changes. These experiments constrained LAI to observed values in specific regions, while using model-prognosed values elsewhere. The results show that the ENSO amplitude is particularly sensitive to LAI over South America, where the model overestimates LAI along the west coast.

We conclude that the underlying mechanism is as follows: increased LAI over South America induces surface cooling due to enhanced latent heat release. This modifies the tropospheric circulation, weakening the local Walker circulation over the Andes and consistently altering the SST distributions. The resulting SST warming off the coast of Peru enhances the convective response to SST anomalies, strengthening the effective Bjerknes feedback and amplifying ENSO.

Introduction

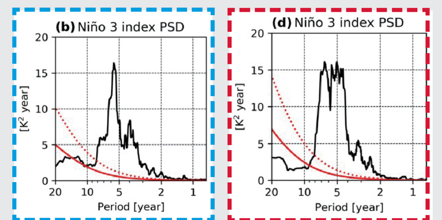


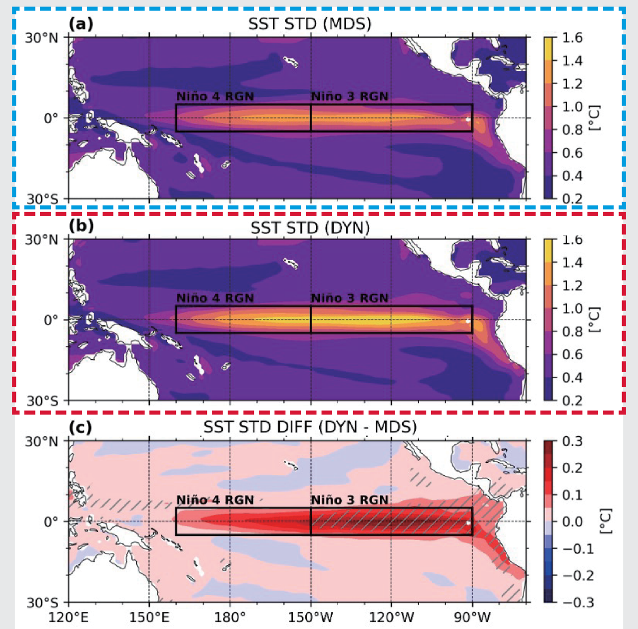


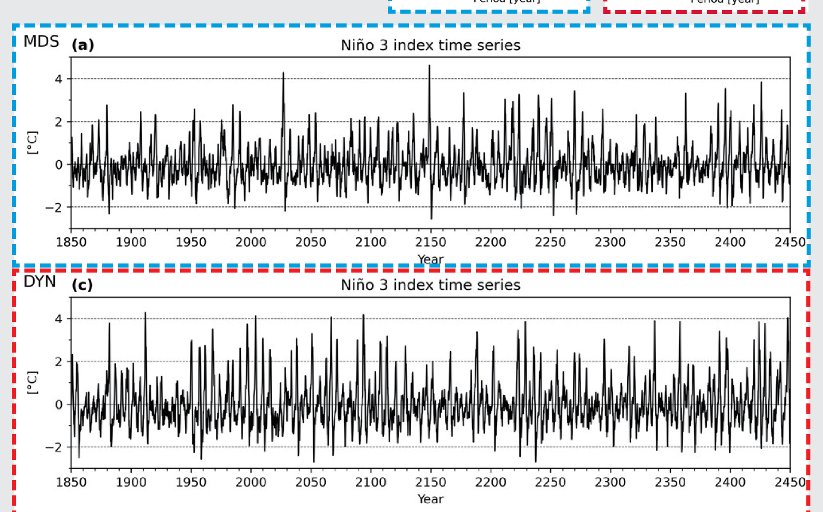
MIROC5.2 **Prescribed LAI climatology** based on MODIS observations.

MIROC-ES2L LAI is **interactively simulated** with VISIT-e.

El Niño-Southern Oscillation (ENSO) is more pronounced when LAI is simulated. We tested different LAI settings under the Pre-Industrial boundary condition to clarify the reason.

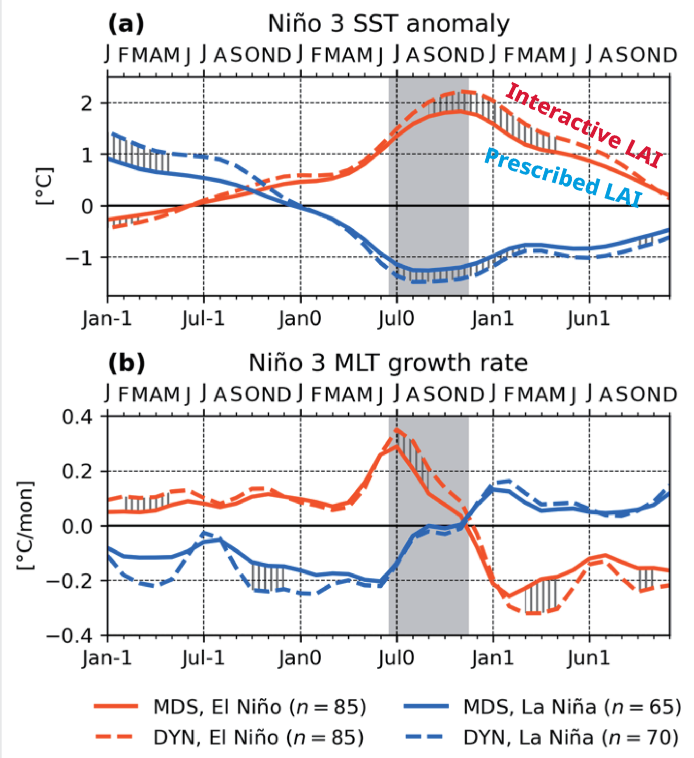


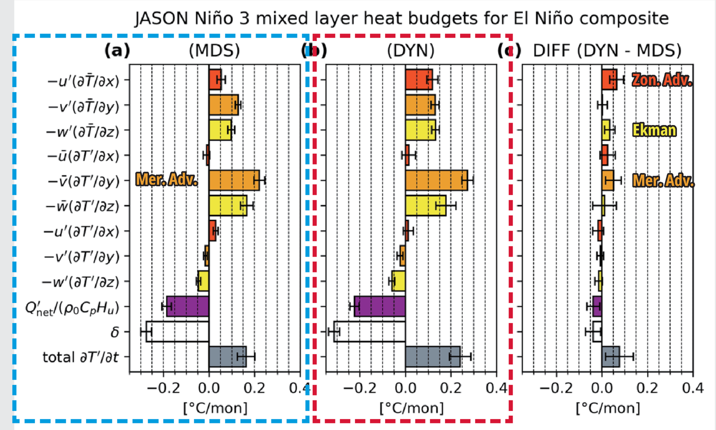




Prescribed vs. Interactive LAI

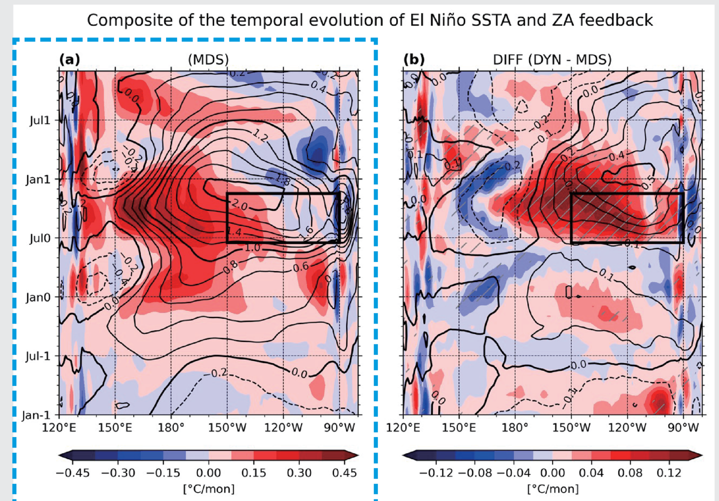
El Niño composite analysis

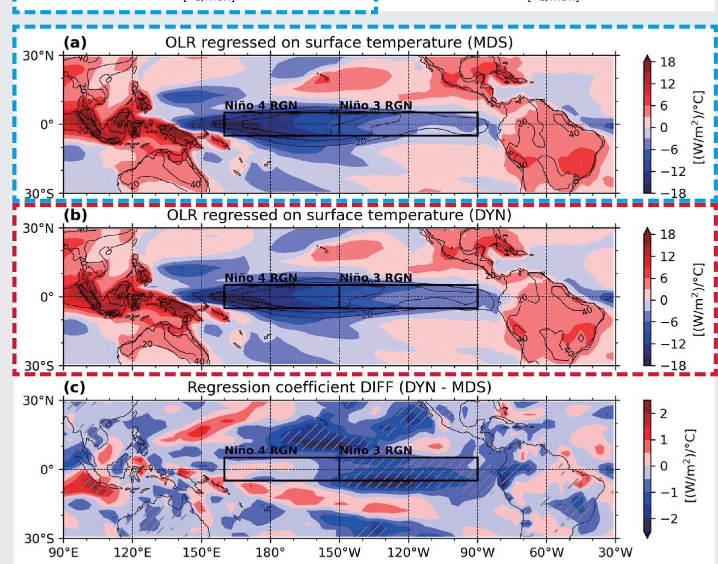




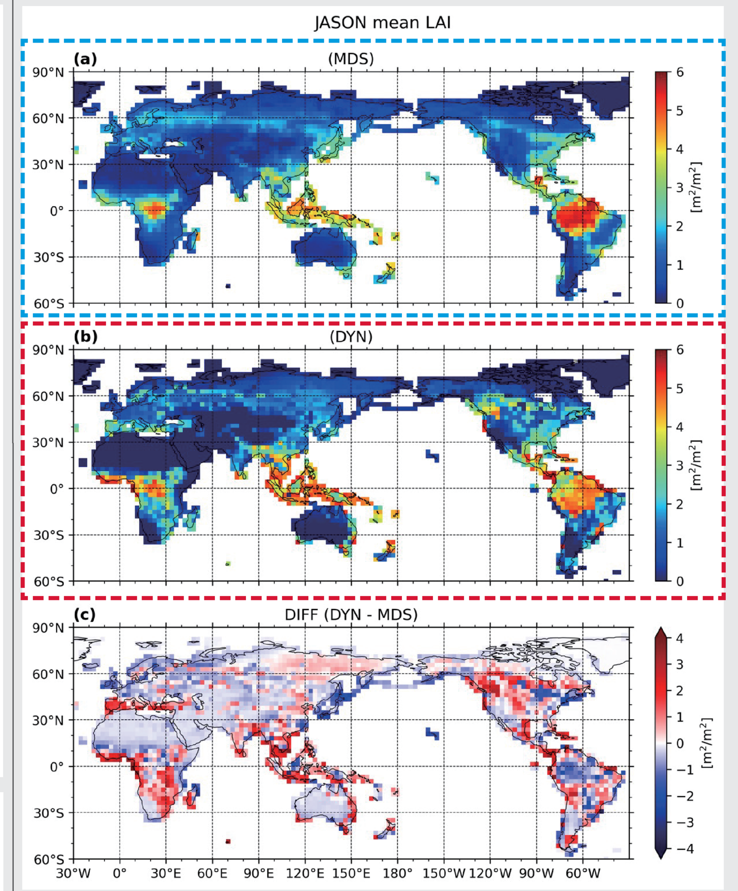
$$\frac{\partial T'}{\partial t} = -(\boldsymbol{v}' \cdot \nabla \bar{T} + \bar{\boldsymbol{v}} \cdot \nabla T' + \boldsymbol{v}' \nabla T') + \frac{Q'_{tot}}{\rho_0 C_p H_m} + \delta.$$

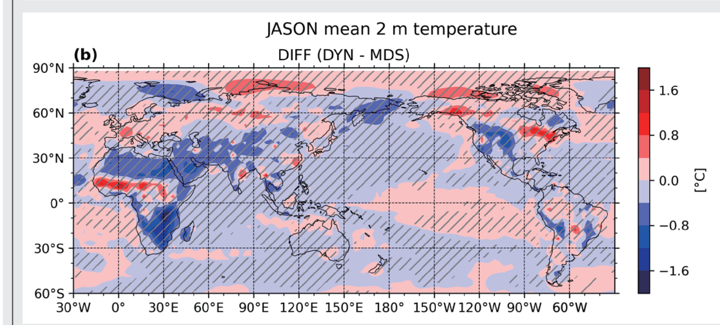
- **El Niño composites** were analysed for each simulation.
- Differences in the El Niño growth rate were attributed to **zonal advective**, **Ekman**, and **meridional advective** feedbacks.
- **Anomalous SST warming** and the associated **convective response** were stronger in the interactive LAI simulation, especially in the **eastern equatorial Pacific**, where convection is typically suppressed by cold SST.



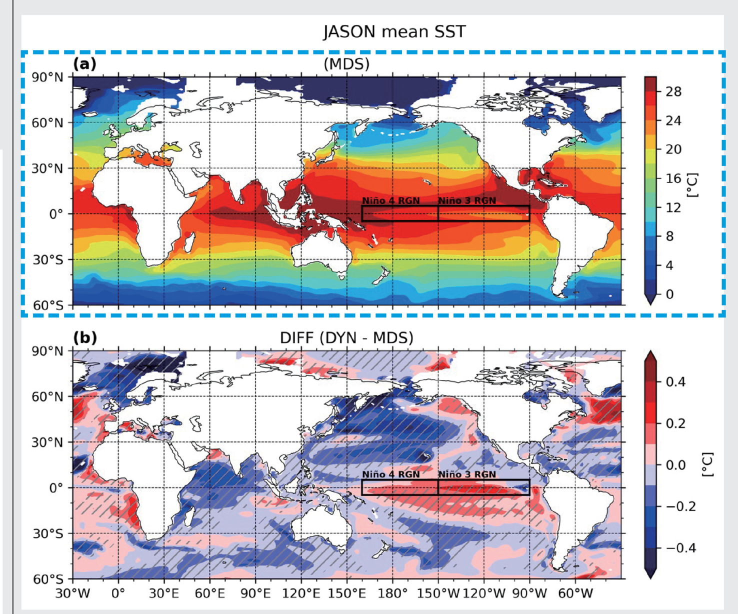


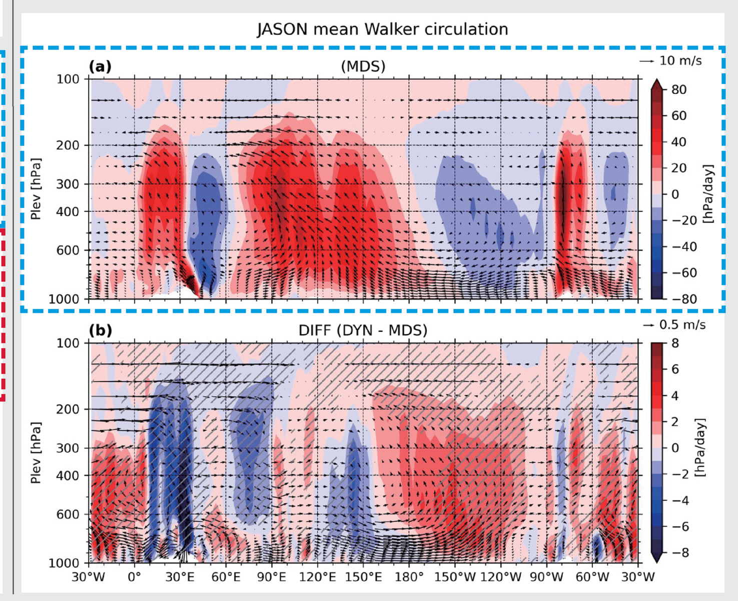
Mean-field change





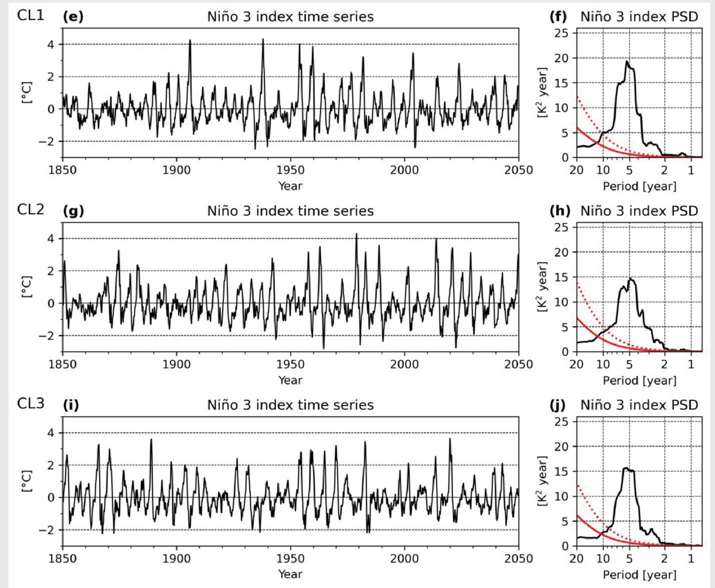
- VISIT-e successfully captures the basic characteristics of the global LAI distribution, although regional overestimates and underestimates are observed.
- **Land surface temperature** is **directly affected by LAI**, but the direction of the effect varies by region.
- The **mean SST** in the equatorial Pacific is **warmer** in the simulation with interactive LAI, and the **local Walker circulation** over the Pacific is consistently **weaker**.



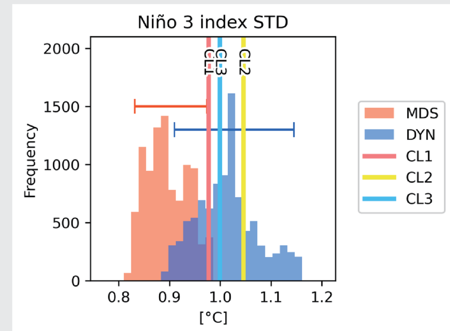


Sensitivity experiments

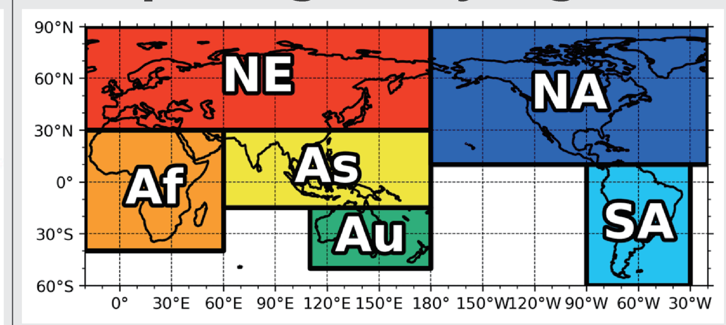
Model-derived LAI climatology



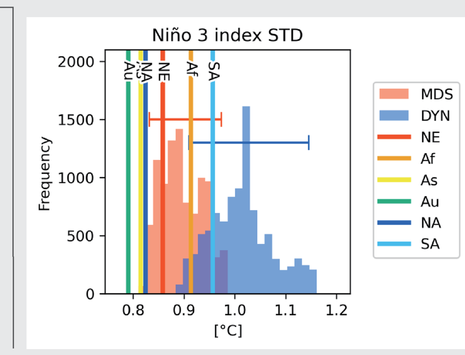
- The **LAI climatology** calculated from the interactive LAI experiment was fed to the model.
- LAI from three different periods were tested to assess statistical variations.
- The standard deviation of the Niño 3 index was **comparable to that in the interactive LAI experiment**.
- This suggests that short-term interactions between LAI and SST are not critical, and that the **mean field** plays a key role in ENSO enhancement.



Replacing LAI by region

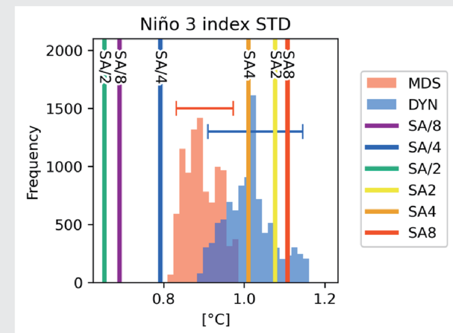


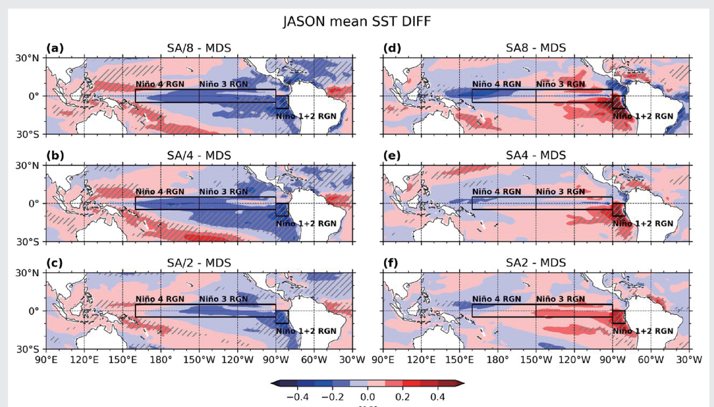
- The **model-derived LAI climatology** was applied only to **certain land areas**, while the MODIS-based observational climatology was used for the remaining areas.
- When applied to **South America**, the model-derived LAI resulted in the **largest standard deviation of the Niño 3 index**.
- In contrast, North America, Southeast Asia, and Africa showed negative effects.

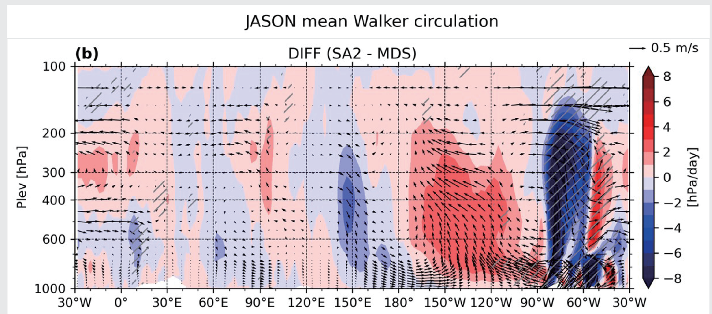


Scaling of LAI in South America

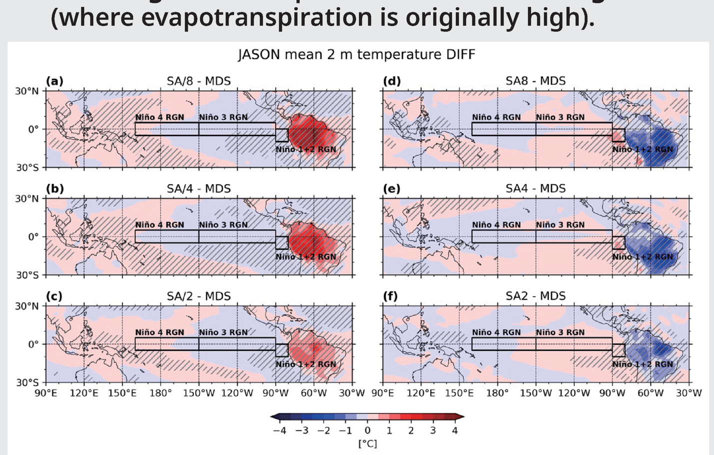
- To assess the sensitivity of the mean field to **LAI over South America**, the observed LAI data were scaled by factors of 1/8, 1/4, ..., 4, and 8.
- The **standard deviation of the Niño 3 index increased** (decreased) significantly with **higher** (lower) **LAI** over South America.
- The relationship between LAI scaling and the amplitude of the Niño 3 index is non-linear.



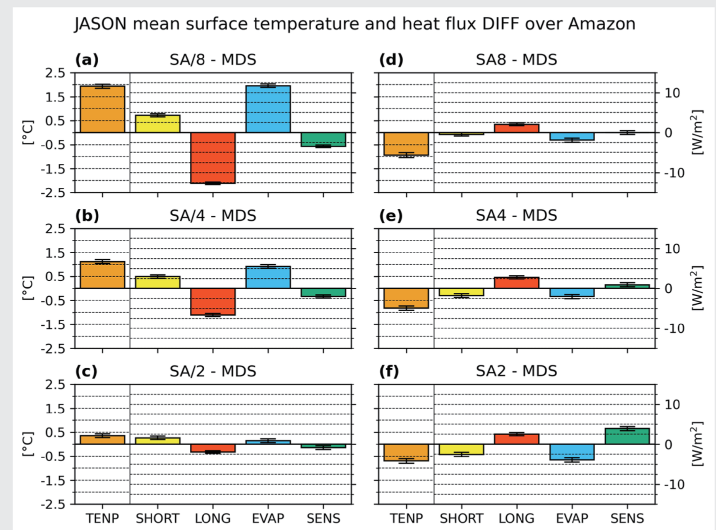


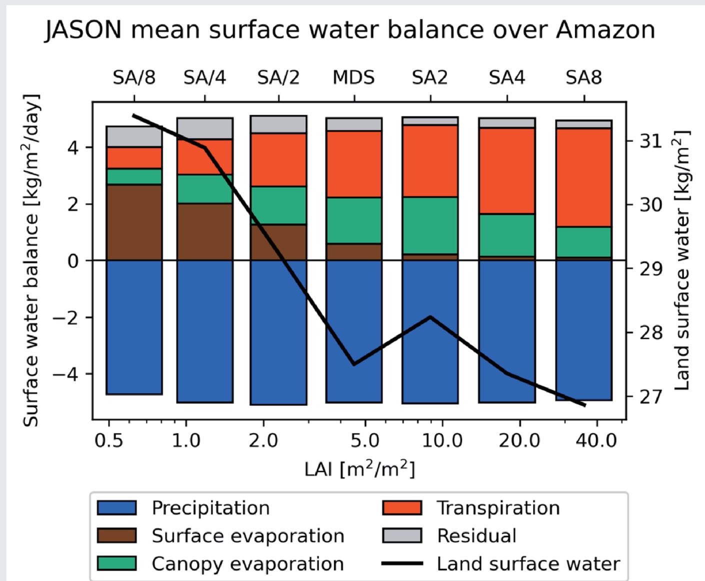


- As the LAI over South America was increased (decreased), **the mean SST** in the eastern tropical Pacific **increased** (decreased), and the **local Walker circulation** was **consistently weakened** (strengthened).
- On land, an **increase** (decrease) in **LAI** led to a **cooling** (warming) of the land surface.
- The **cooling** was more pronounced in **dry regions** (where evapotranspiration is originally low), while the **warming** was more pronounced in **humid regions** (where evapotranspiration is originally high).



- As LAI increased, the **land surface cooled** due to **reduced solar radiation** and **increased evapotranspiration**.
- An increase in LAI leads to **higher stomatal conductance** and, hence, **increased transpiration**.
- This cooling and moistening of the Amazon forest also appears to affect cloud cover, resulting in reduced incoming shortwave radiation.





Discussion and Conclusions

- **Prescribed LAI** vs. **Interactive LAI**:
  - The **SST anomaly** and the **associated convective response** over the **cold tongue region** were enhanced in the climate simulations with the interactively prognosed LAI, than with the prescribed LAI based on observations.
  - **Warmer SST** and **weaker local Walker circulation in the mean field** over the eastern equatorial Pacific supported stronger convective feedbacks.
  - There were **LAI overestimates and underestimates** at the regional level, and this affected **land surface temperature**.
- **Model-derived LAI climatology simulations** produced **strong El Niños**, as did the interactive LAI simulation.
- Replacing LAI by region, SST variability in the eastern equatorial Pacific showed the greatest sensitivity to **South American LAI**.
- Sensitivity experiments with increasing and decreasing South American LAI showed that:
  - More LAI in tropical South America leads to **more evaporative cooling** and a **cooler land surface**.
  - **Local Walker circulation** over Amazon and eastern equatorial Pacific **weakens** when increasing South American LAI.
- Based on the results above, we conclude the following mechanism: An **increase in LAI** along the **west coast of South America** leads to **surface cooling** due to **enhanced latent heat release**. This cooling alters the **tropospheric circulation** by **weakening the local Walker circulation** over the Andes. As a result, **SST patterns shift**, with **warming occurring off the coast of Peru**. This warming **intensifies the atmospheric convective response** to SST anomalies, which in turn **strengthens the effective Bjerknes feedback** and **amplifies ENSO**.

Problems with canopy height and land-atmosphere coupling

- **Land cover** is **fixed** based on observations in both the AOGCM and ESM versions of MIROC.
- **Vegetation height** is given as a **constant** depending on the land cover.
- **Bulk coefficients** for **momentum**, **heat**, and **moisture exchange** are calculated as a function of **LAI**, **canopy height**, and **lowest model level height of the atmosphere** (based on Watanabe 1994).
- The lowest model level height in MIROC is about **20 m**, which is **much lower than the canopy height** of a tropical forest.
- In these regions, **the calculation of bulk coefficient fails** and the flux dependence on LAI and vegetation height is not properly represented.
- **Reconstruction of the land surface-atmosphere coupling scheme** is needed to properly estimate the quantitative effect of LAI change on land surface temperature, local atmospheric circulation, and the mean state of the upper layer of the ocean.