S1 JULES-ES model description (Land-use Change impact on Carbon Cycle):

a. Vegetation distribution

Land use change in JULES-ES impact on vegetation distribution by modifying the competition term on the simulation of PFT distribution. Here in Equation (S1).

$$\frac{dv_i}{dt} = \frac{\lambda \prod v_*}{C_{vi}} \left\{1 - \alpha a_i - \sum_j c_{ij} v_j\right\} - \gamma_v v_* - \beta_i v_* \qquad \text{(S1)}$$

Here, v_i denotes the area of grid covered by PFT i . The rate of change in v_i depends on the carbon available for increasing the PFT area ($\lambda \prod v_*$), and the associated carbon cost, determined by the carbon density (C_{vi}). Four terms balance the constant expansion of PFTs:

1. **Vegetation Loss** ($\gamma_v v_*$): Represents vegetation loss from mortality process, not related to competition
2. **Fire disturbance** ($\beta_i v_*$): Accounts for vegetation loss due to fire
3. **Competition amongst PFTs** ($\sum_j c_{ij} v_j$): The dominant PFT will out compete the others.
4. **Land-use change** (αa_i): Represent the competition caused by Land-use change

In the context of land-use change, α is the disturbed fraction, and a_i equals 1 for non-woody PFTs and 0 for woody PFTs. Woody PFTs are restricted from growing in the disturbed fraction, while non-woody PFTs can grow anywhere, including disturbed areas, where they are considered agricultural grasses. These grasses are physiologically identical to natural grasses but are labelled differently. The value of α can change over time. When α increases, natural grasses are reclassified as agricultural grasses, and woody PFT areas are replaced first by bare soil, then potentially by non-woody PFTs if viable. Conversely, as α decreases, agricultural grasses are reclassified as natural grasses, and woody PFTs can re-expand into the grid.

b. Soil carbon store

Land-use change, together with fire, affect the soil carbon store by altering the flux of vegetation-to-soil litter. This litter flux is composed of:

- Local litterfall from leaf, root and stem turnover.
- Litter produced by disturbances and competition.

The effect of land-use change, and fire are integrated into the following Equation (S2):

$$\Lambda_{CvLoss} = \sum_i v_i \left(\Lambda_{li} + (\gamma_{vi} + \beta_i) C_{vi} + \Pi_i \sum_j \left(\alpha a_i + c_{ij} v_j\right)\right) \qquad \text{(S2)}$$

Here, Λ_{CvLoss} represents vegetation carbon loss. However, not all carbon lost enters the soil carbon pools; some loss due to land-use change is diverted to wood-product carbon pools. The litter generated by land-use change (Λ_{LUC}) is calculated using the disturbed fraction (α_{-1}) from the previous time step, as shown in Equation (S3):

$$\Lambda_{LUC} = \Lambda_{CvLoss} - \sum_i v_{LUC,i} \left(\Lambda_{li} + (\gamma_{vi} + \beta_i) C_{vi} + \Pi_i \sum_j \left((\alpha - \alpha_{-1}) a_i + c_{ij} v_{LUC,j}\right)\right) \qquad \text{(S3)}$$

Here, v_{LUC} is the PFT area computed from Equation (1) using $\alpha = \alpha_{-1}$. The litter produced by land-use change is distributed between soil carbon pools and wood-product pools. The below-ground carbon portion, determined by root carbon (C_v), is added to the soil carbon pool, while the remaining above-ground carbon is allocated to the wood-product pool.

S2 Resampling Rationale:

In this research, the 30 meters dataset of cropland changed has been resample to 0.5 degree resolution. This approach has been conducted to make it consistent with other models. Although this might reduce the accuracy of spatial detail, it did not massively change the total cropland each year. For example, cropland on MB2 in 2000 is 38.51046 Mha for 30 meters resolution but it is 39.51675 Mha in 0.5 degree resolution. In 2018, 47.43622 Mha for 30 meters, and 48.49098 Mha in 0.5 degree resolution. The difference can also be observed from the figures bellow.

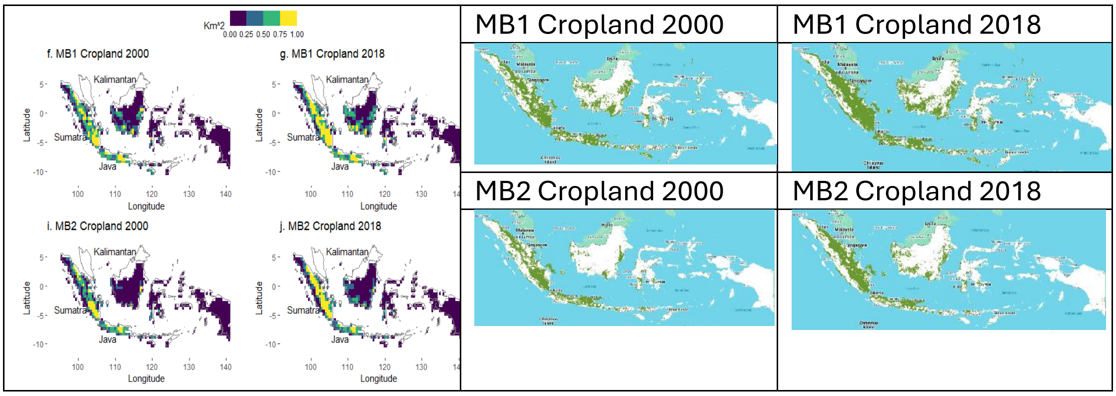

Figure S1 the comparison of 0.5 degree (left) and 30 meters (right) resolution spatial distribibition