Re-assessing global carbon budget by accounting for decadal and interannual variability of the carbon flux in secondary lands

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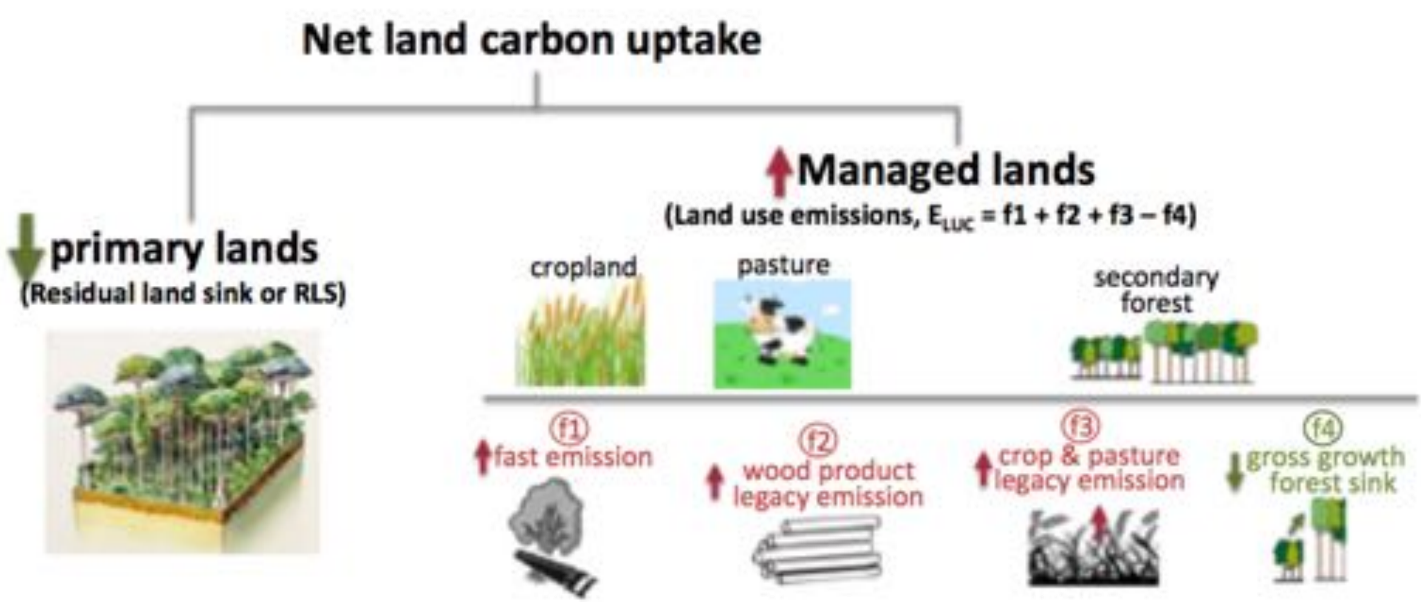
Current issues in estimating land use change emissions (E_{LUC}) in GCP

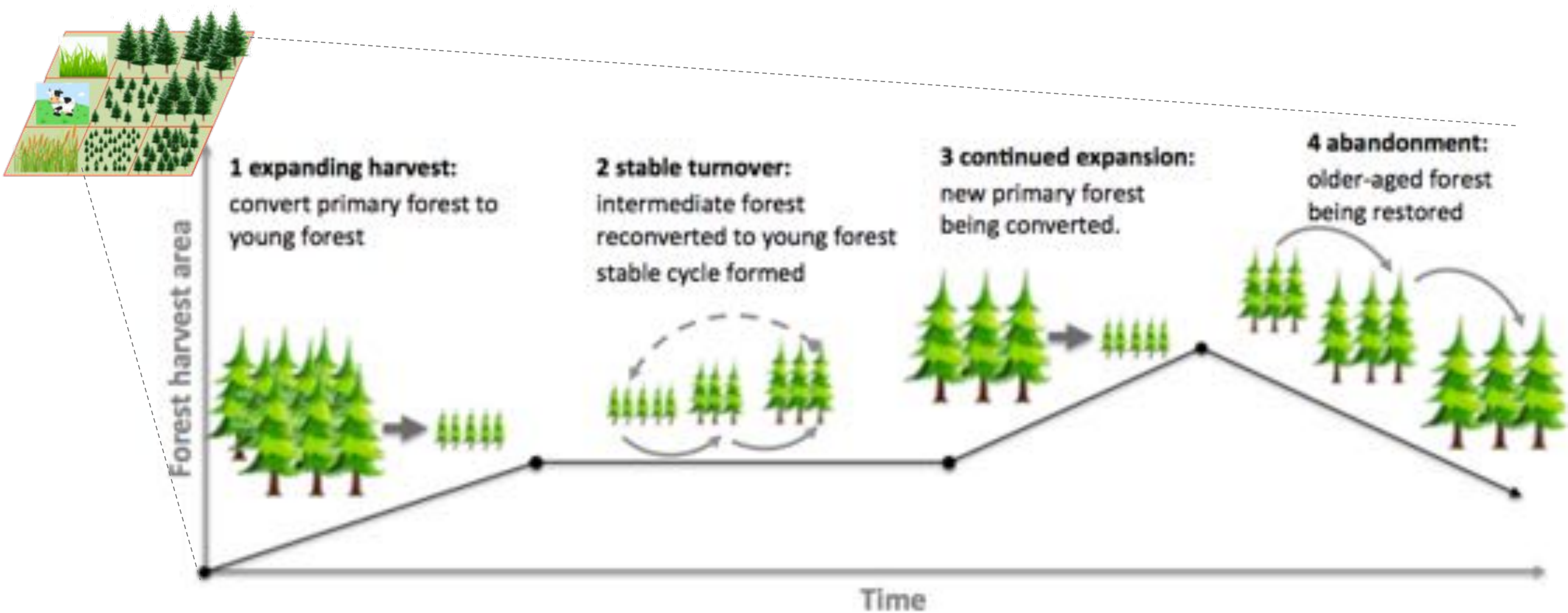
- E_{LUC} is based on a bookkeeping model with interannual variability (IAVs) imposed as that of fire emissions of tropical deforestation and forest degradation from GFED data.
- Good things split in two worlds:
  - DGVMs can account for IAVs in land carbon balance induced by climate variation, but mixing primary and secondary lands and differentiating S2/S3 simulations dampen IAV;
  - Bookkeeping models do not account for all IAV components of E_{LUC}: notably the fluxes of f3 and f4.

  ⇒ **The consequence is that IAVs in E_{LUC} tend to be too small. This leaves a too large IAV in the residual land sink.**

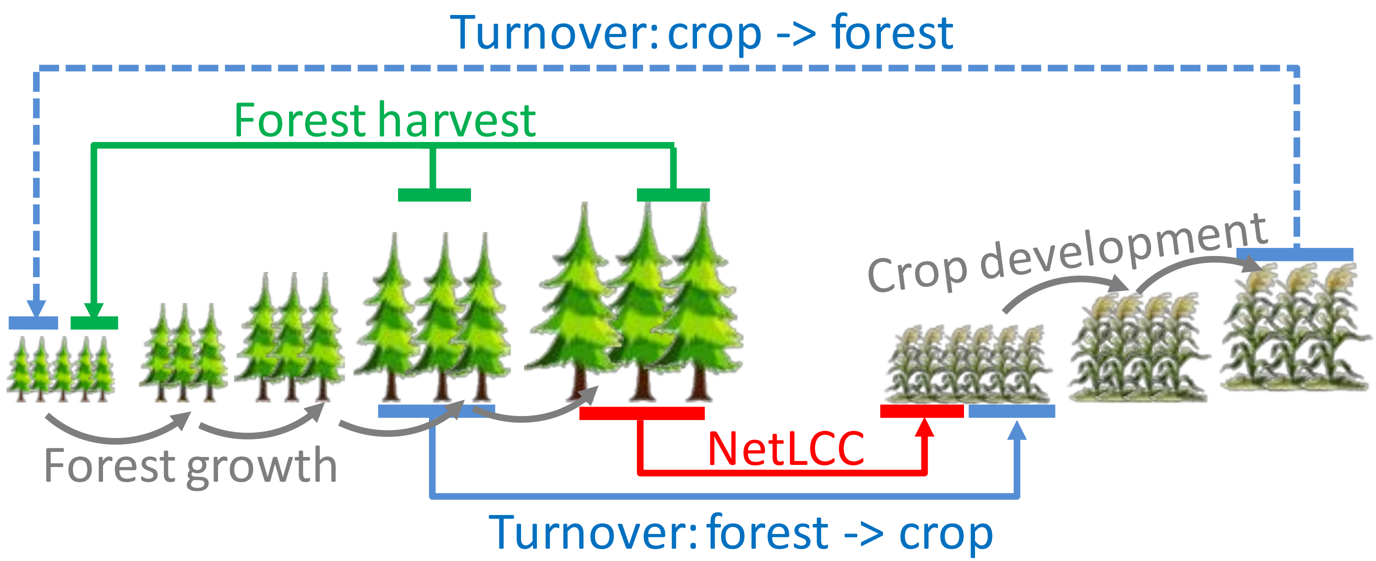


Combine both advantages of DGVM and bookkeeping model

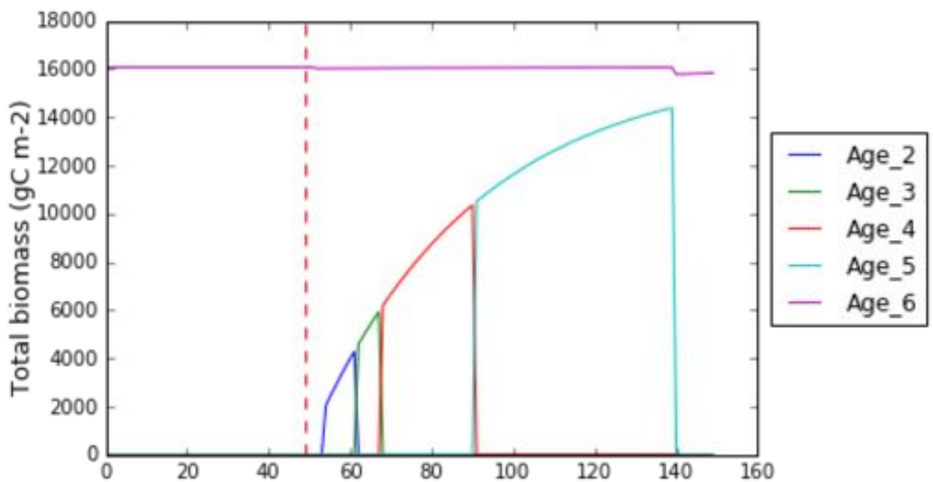
- We developed the ORCHIDEE DGVM to account for sub-grid land cohorts (forest age class; cohorts of cropland, pasture and grassland distinguished by their soil carbon stock)
- The enhanced model feature allows tracking secondary land carbon balance in a similar way as in bookkeeping models, while incorporating all climate variation impact on vegetation carbon cycle — it thus combines both advantages of the two split worlds.



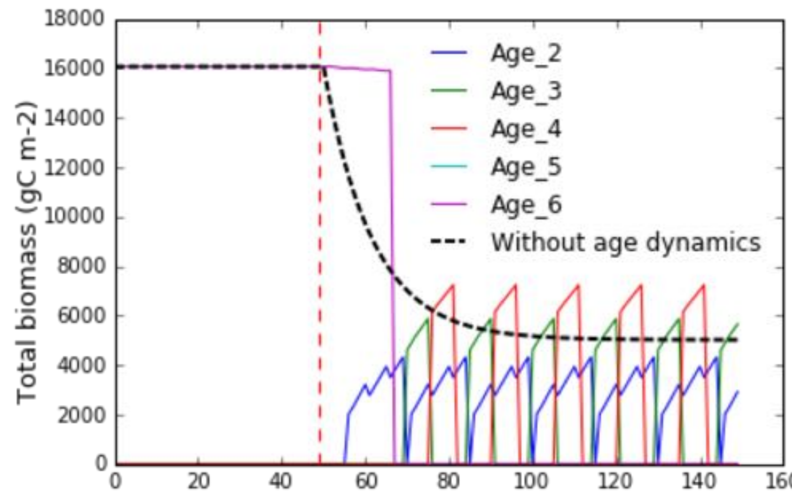
Explicit forest patches with different C stock (age dynamics)



Forest biomass C recovery following **a single LUC event**:
Forest→crop = 0.15; crop→forest = 0.15



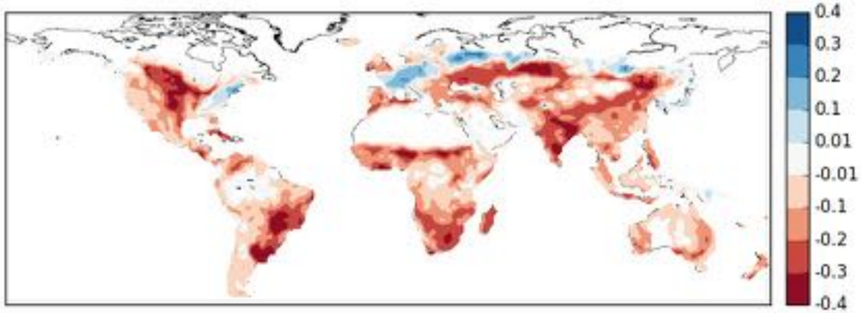
Forest biomass C recovery following **continuous LUC event:**
Forest→crop = 0.05; crop→forest = 0.05 for each year



Forest cover and age distribution impacted by LUC

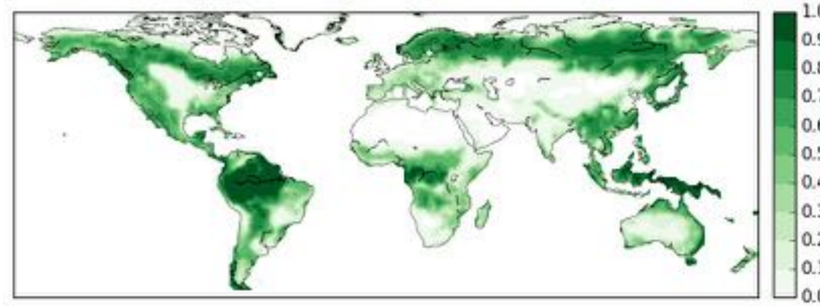
Forest loss for 1501-2005

Decrease in forest area (1501-2005) = 11.8 Mkm^2 (21%)

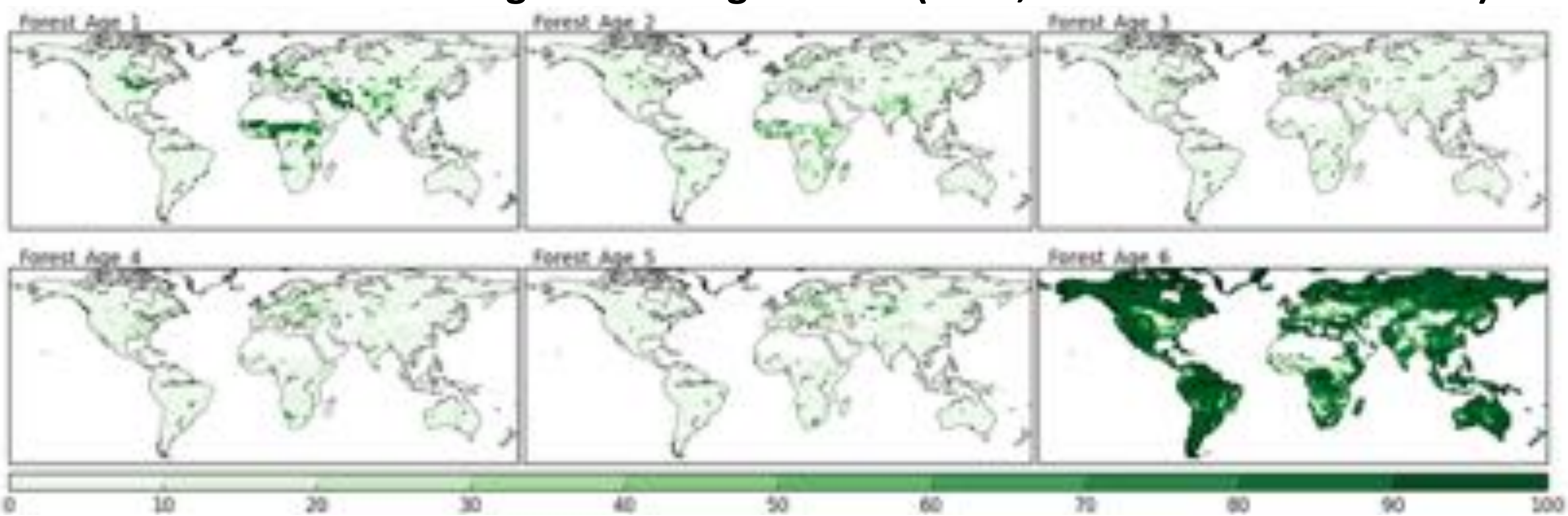


Forest cover for 2005

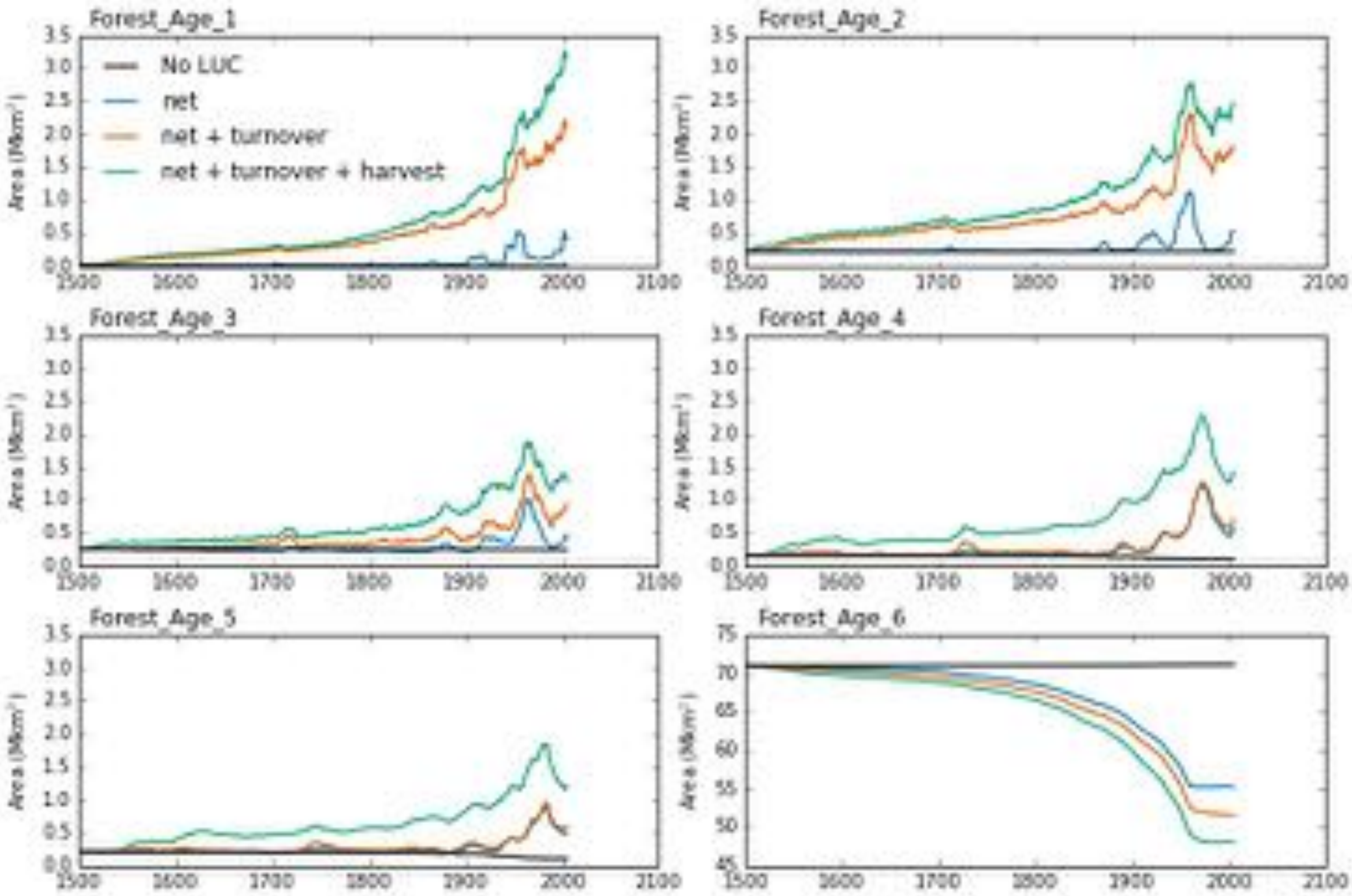
Forest area for 2005 = 56.2 Mkm^2 (21%)



Distribution of forest among different age classes (2005, net + turnover + harvest)

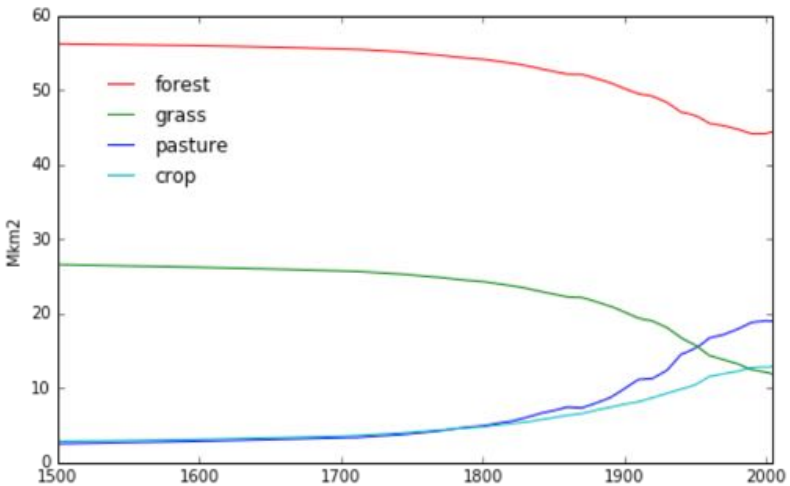


Forest age dynamics over time

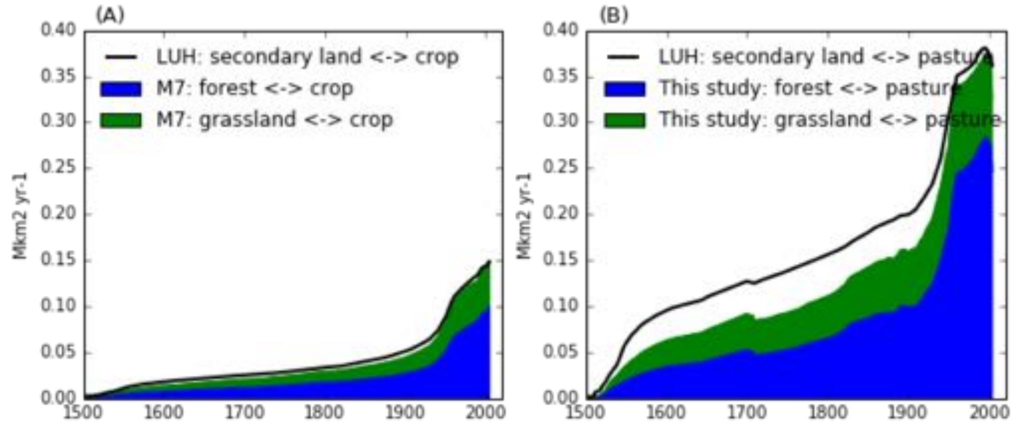


Temporal pattern of historical LUC activities (1501-2005)

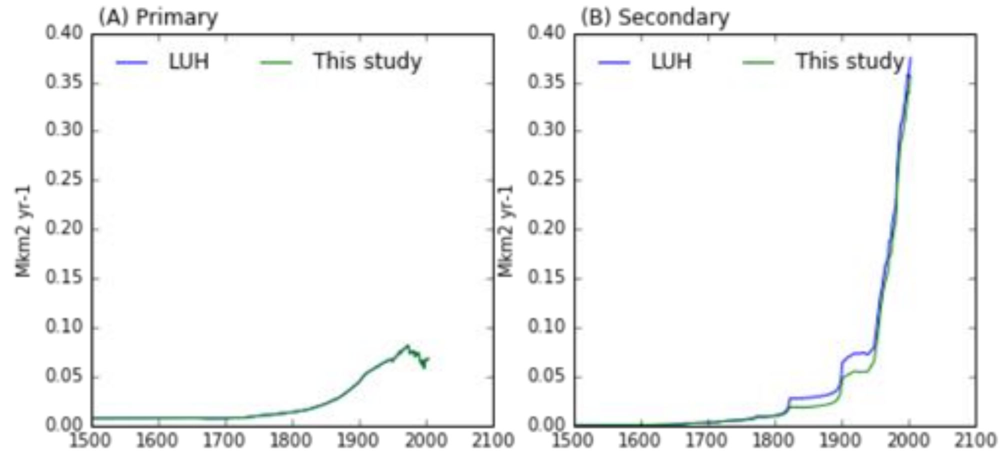
Net land cover change



Land turnover

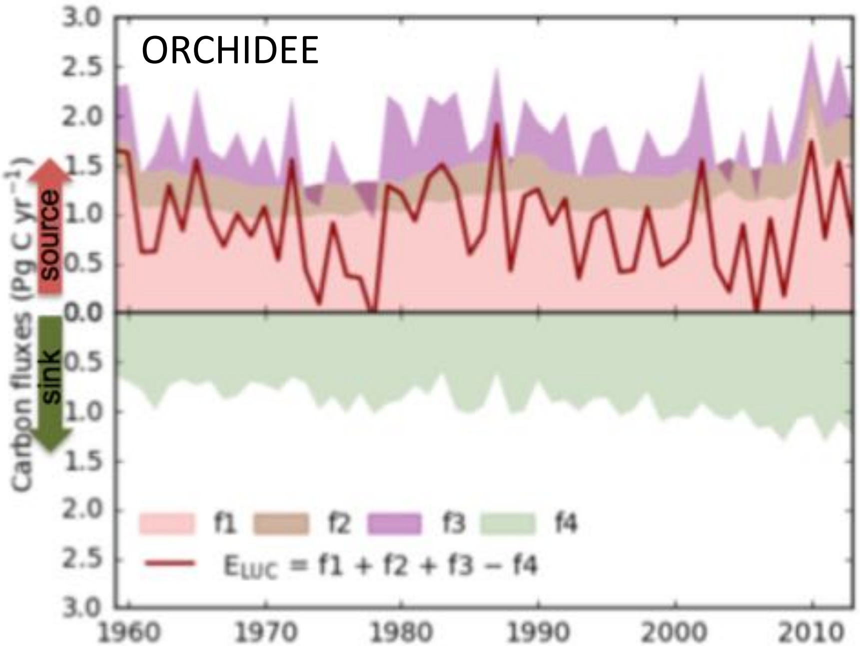


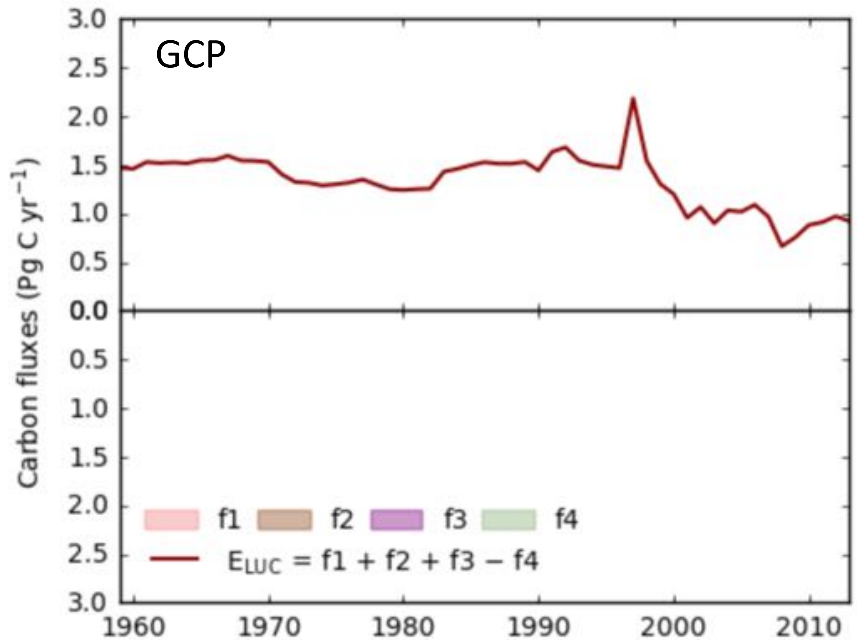
Forest wood harvest



The first-order driving factor for temporal pattern of LUC emissions are the magnitudes of LUC activities over time, be it forest loss, or land turnover or wood harvest, with the rest partly driven by climate variation.

ORCHIDEE-simulated E_{LUC} versus the GCP estimate





Variance (E_{LUC}) = 0.23 Pg C yr^{-1}

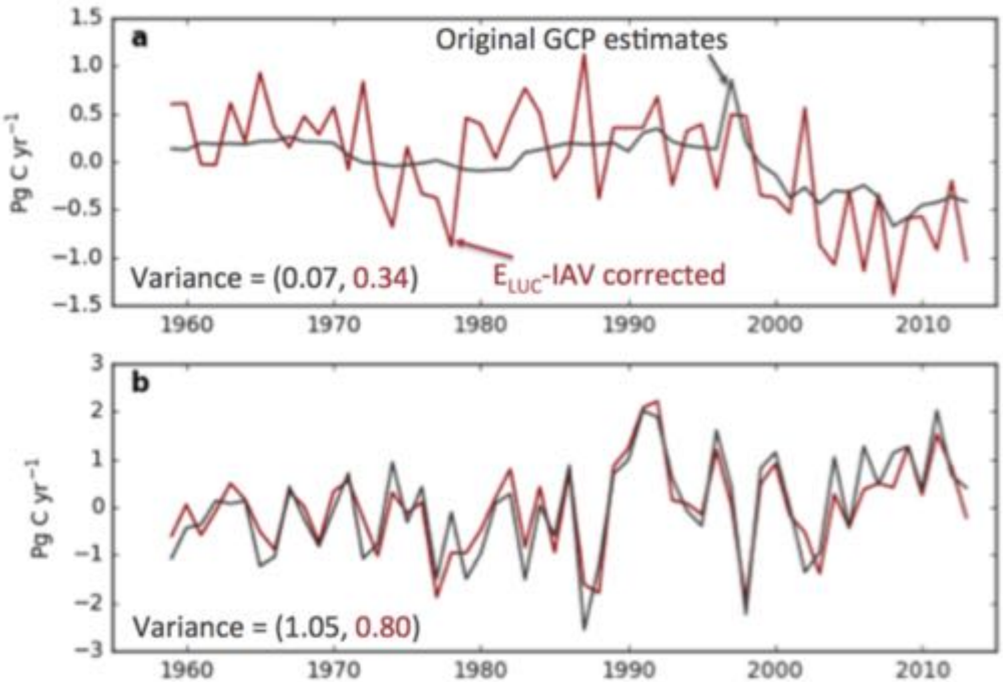
Variance (RLS) = 0.60 Pg C yr^{-1}

Variance (E_{LUC}) = 0.08 Pg C yr^{-1}

Variance (RLS) = 1.07 Pg C yr^{-1}

$\Rightarrow$ ORCHIDEE simulates a higher IAV of E_{LUC} and correspondingly a lower IAV in the residual land sink (RLS).

Adjust GCP E_{LUC} by ORCHIDEE simulation



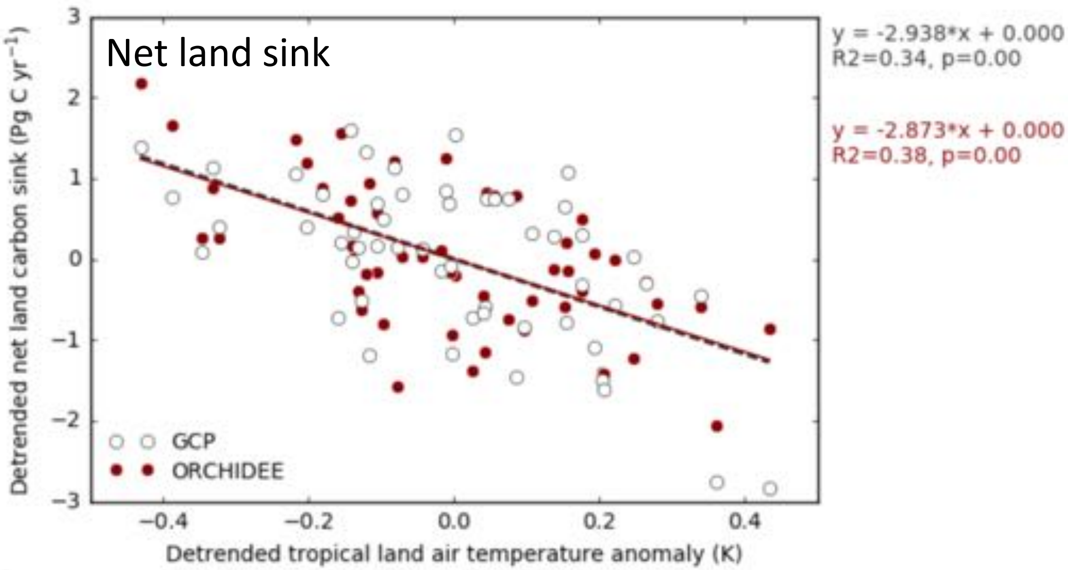
$S_{net} = RLS - E_{LUC}$

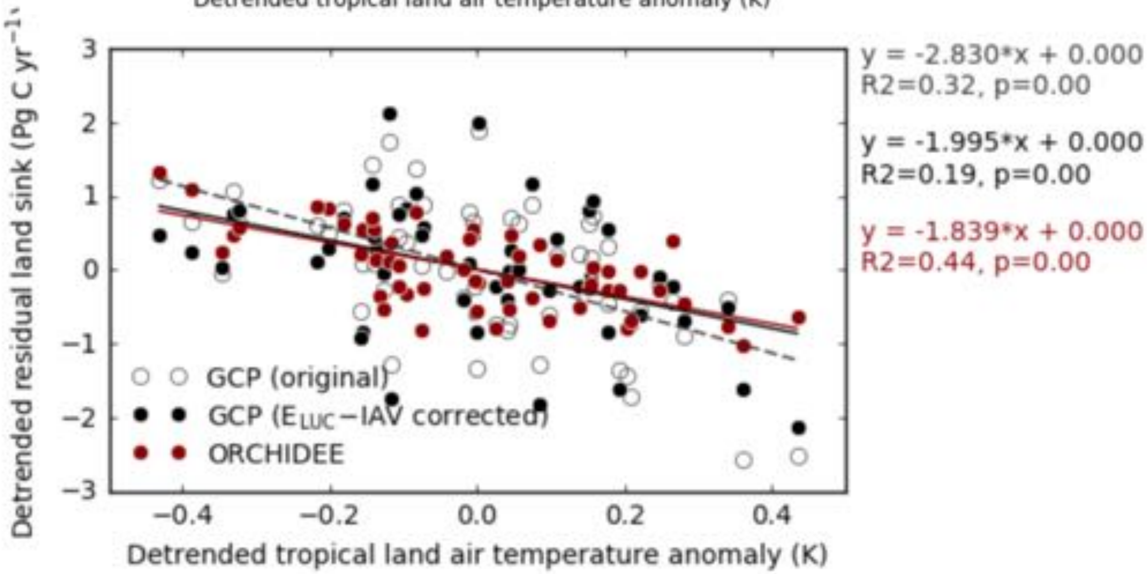
$Var(S_{net}) = Var(RLS) + Var(E_{LUC}) - 2Cov(RLS,E_{LUC})$

Variance (Pg C yr^{-1})	Original GCP	E_{LUC}-IAV corrected
S_{net}	1.22 (100%)	1.22 (100%)
E_{LUC}	0.07 (6%)	0.34 (28%)
RLS	1.05 (86%)	0.80 (66%)
-2Cov(RLS, E_{LUC})	0.10 (8%)	0.08 (7%)

⇒ Now, 28% of IAVs in the net land uptake originate from managed lands against 66% from natural lands, whereas a much larger contribution from natural lands is given by GCP estimates.

Lower sensitivity of RLS to tropical land temperature





⇒ A smaller sensitivity of RLS to tropical T than by original GCP estimates.

Conclusions

- Vast area of secondary lands resulting from historical land use change have large year-to-year variations in their carbon balance and they contribute to IAVs of E_{LUC}.
- Accounting for full IAVs in E_{LUC} leads to a different attribution of the net land sink into the two components of E_{LUC} and RLS on primary lands than original GCP estimates — a larger contribution from E_{LUC} and smaller one from natural primary lands.
- The temperature sensitivity of the residual land sink might be over-estimated by previous GCP estimates.
- More efforts are needed investigating spatial distribution of secondary lands their temporal variation for a full assessment of their impact on global carbon cycle dynamics.