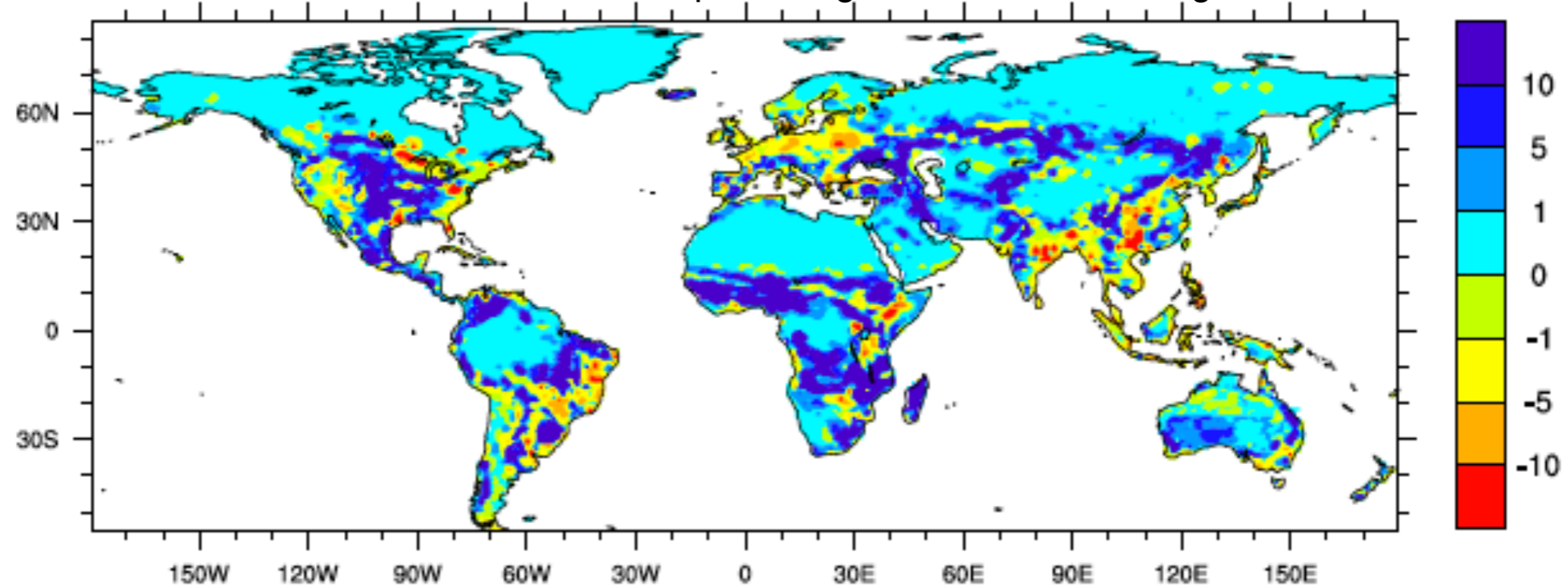


# Coupling the land use decisions and carbon cycles of earth system and integrated assessment models

Additional afforestation as percentage of land area within grid cell



Alan Di Vittorio, Ben Bond-Lamberty, Louise Chini, Jiafu Mao, Kate Calvin, Andy Jones, Xiaoying Shi, Pralit Patel, John Truesdale, Anthony Craig, Bill Collins, Jae Edmonds, George Hurtt, Allison Thomson, Peter Thornton, Yuyu Zhao, Marcia Branstetter, Enhao Du, Jennifer Holm



DOE BER Climate Modeling PI Meeting  
May 12-14, 2014



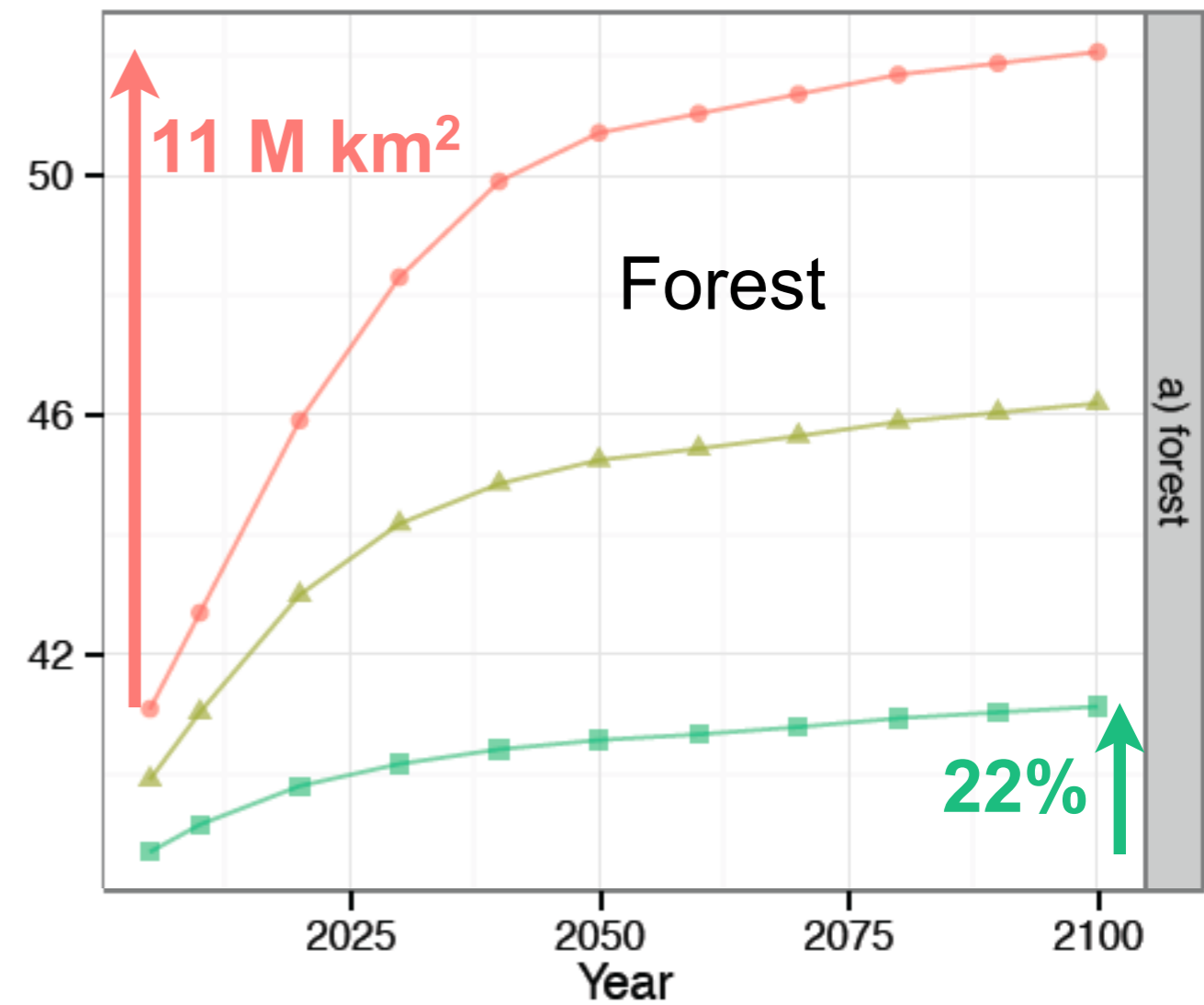
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## Main Points

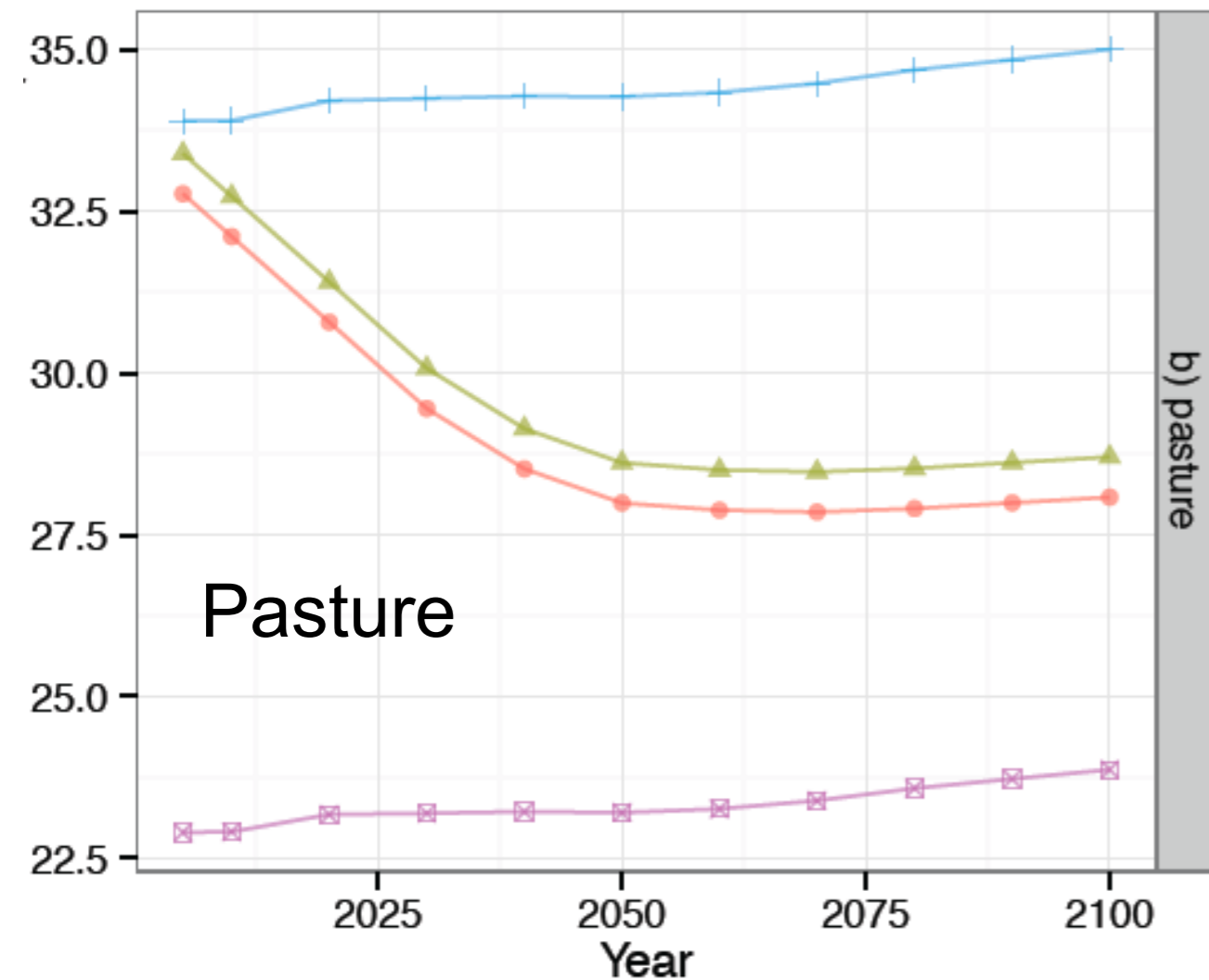
- We have successfully implemented 2-way land coupling between GCAM and CESM
- Climate feedback from CESM to GCAM is robust
- Inconsistencies in land cover effectively change the scenario passed from GCAM to CESM and significantly affect the global carbon cycle
  - Extremely challenging problem
  - Similar inconsistencies exist for other CMIP5 models
  - Not necessarily limited to RCP4.5
  - iESM needs land constancy and a single carbon cycle

# CMIP5 RCP4.5 global area (million km<sup>2</sup>)



## Legend

- RCP4.5
- ▲ GLM
- CLM forest PFTs
- + CLM shrub and grass PFTs
- ⊠ CLM grass PFTs

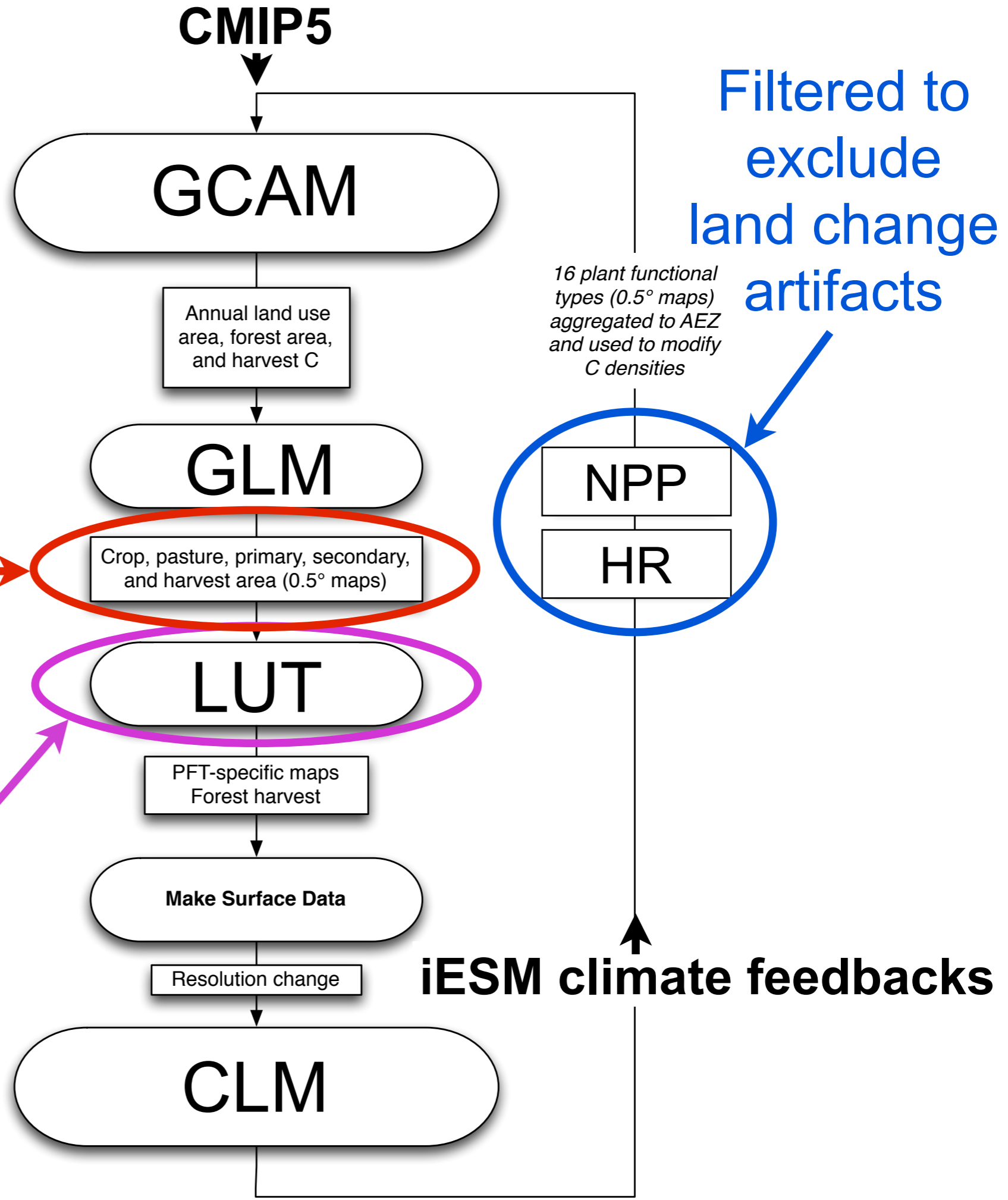


4

# iESM land coupling

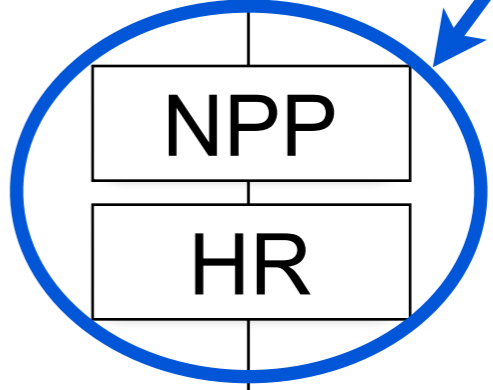
No land cover info!  
Only crop, pasture,  
primary, secondary

New Land Use  
Translator  
(LUT)



Filtered to  
exclude  
land change  
artifacts

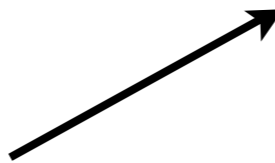
*16 plant functional  
types (0.5° maps)  
aggregated to AEZ  
and used to modify  
C densities*



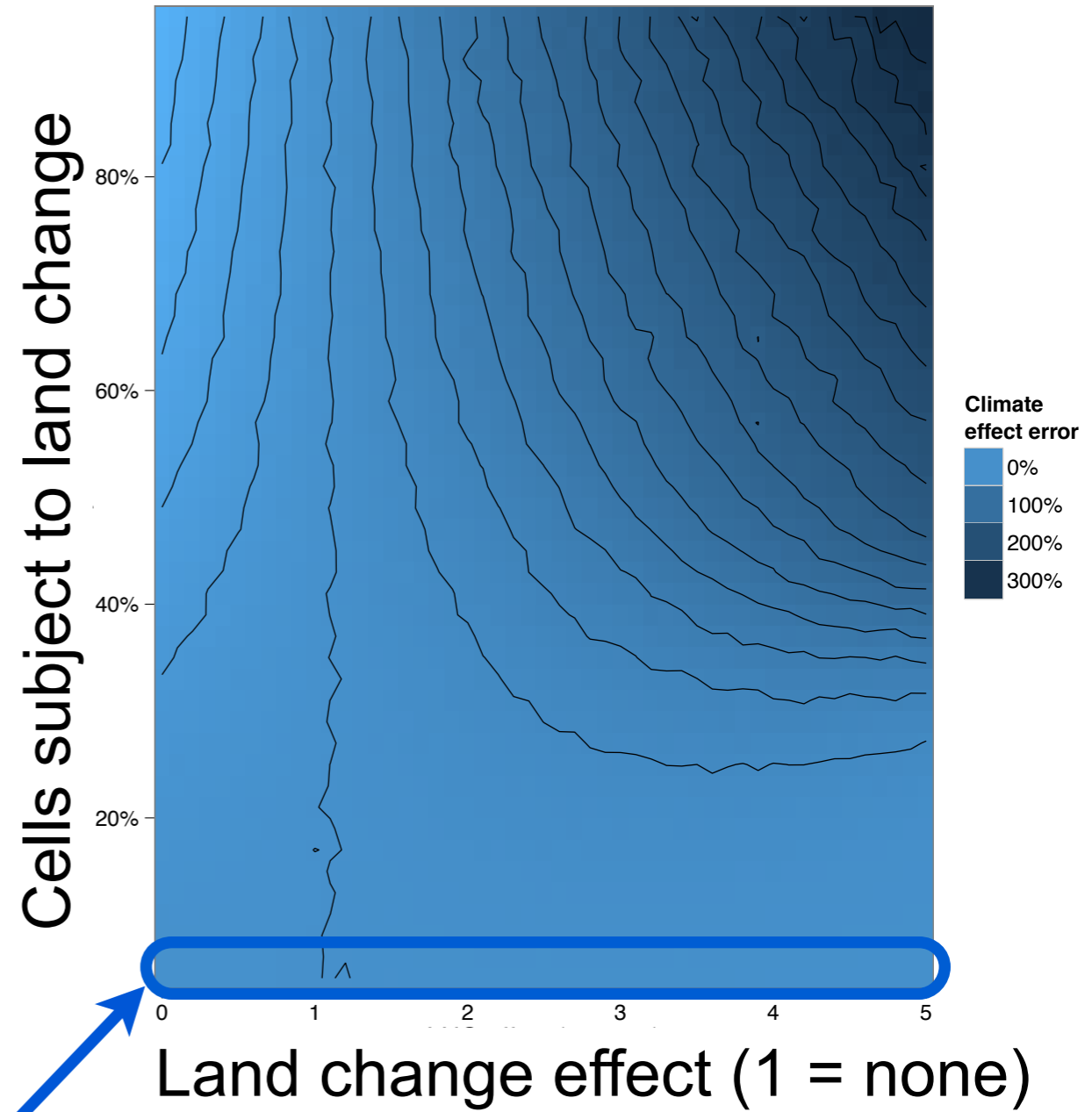
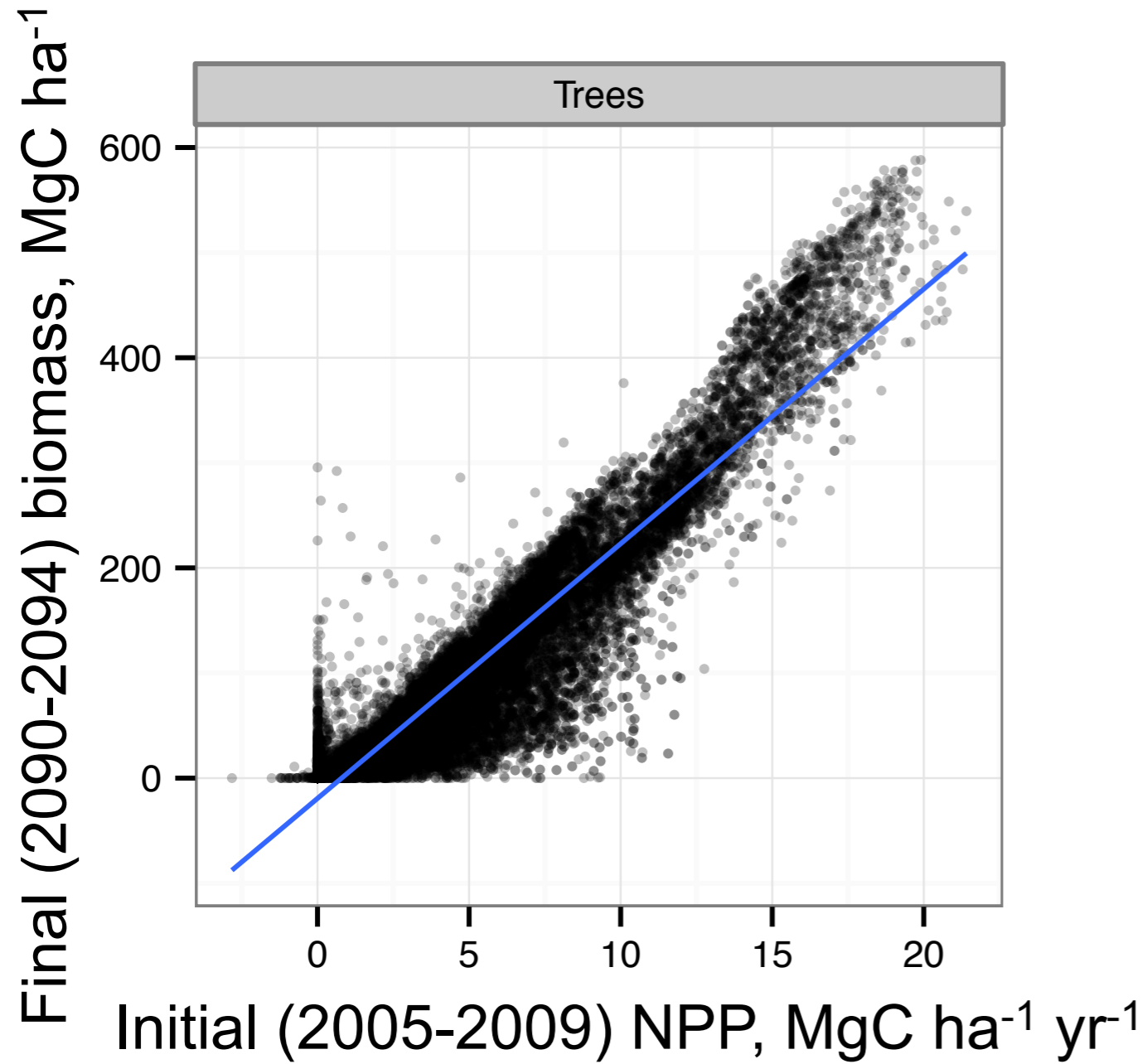
**iESM climate feedbacks**



# Add trees when cropland and pasture areas are reduced

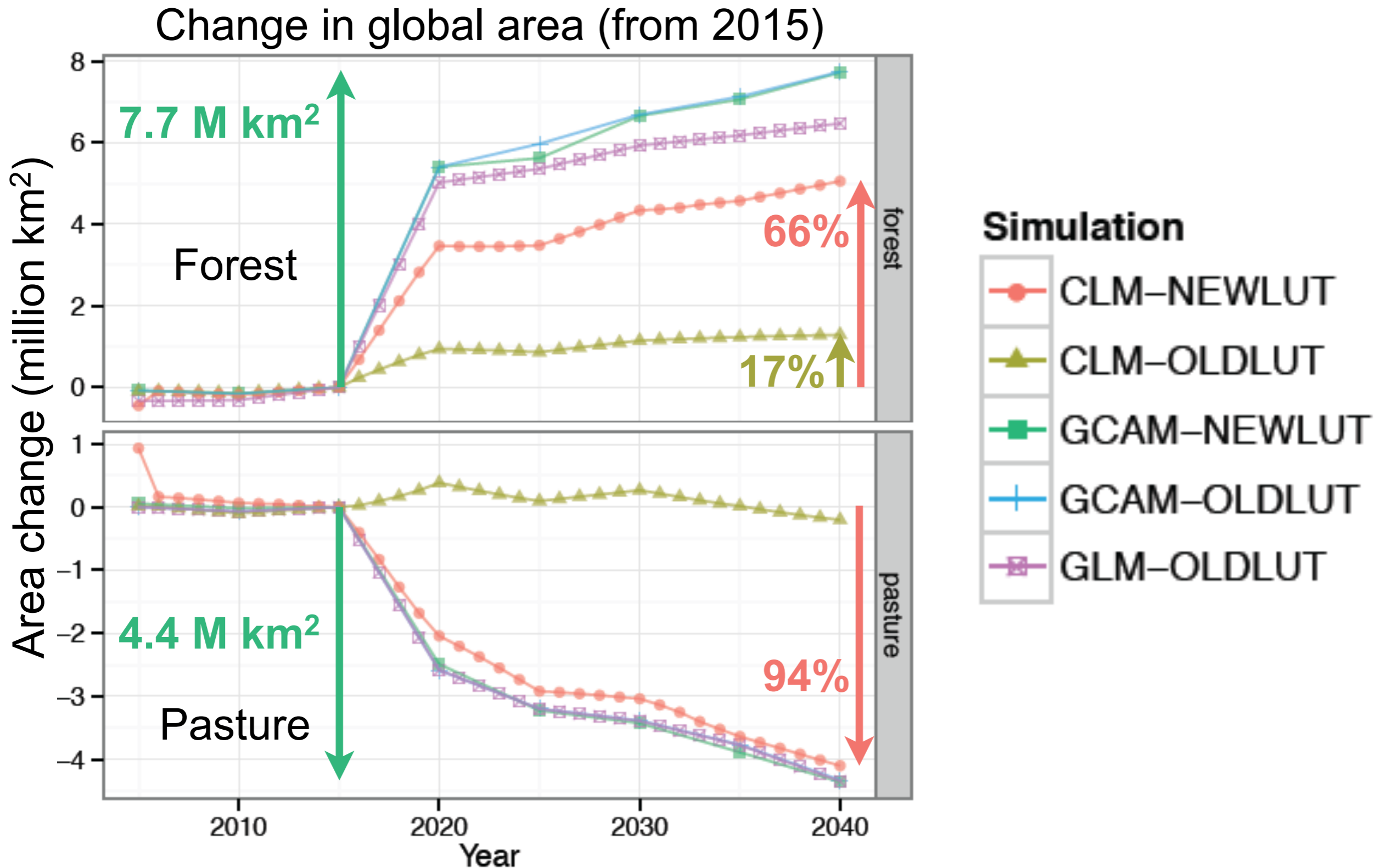


# Robust climate feedback implementation



iESM cells removed

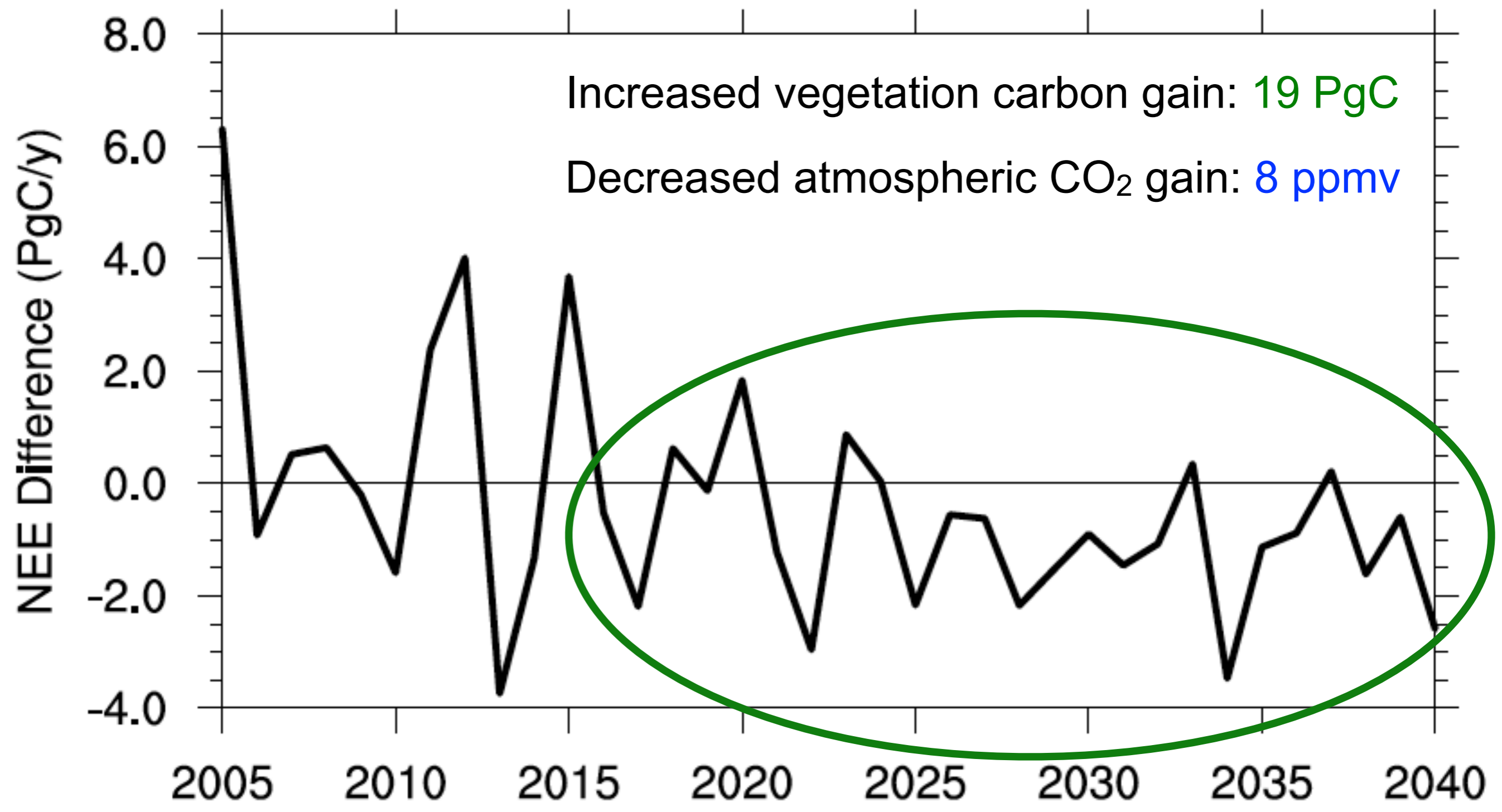
# iESM transmits 66% of the afforestation to CLM





# Additional land C uptake due to afforestation

Global NEE: NEWLUT minus OLDLUT





## Summary

- iESM successfully implements 2-way land coupling between GCAM and CESM
- Robust climate feedback implementation
  - GCAM (potential) vs CESM (actual) carbon
- Land cover inconsistencies across models significantly affect the global carbon cycle
  - CESM-only modification helps, but not sufficient
    - ~60 out of 100 PgC increase in veg. carbon
    - ~25 out of 40 ppmv decrease in atm. CO<sub>2</sub>
- Land cover inconsistencies alter the prescribed scenario

Thank you!

Figures are from:

Di Vittorio et al. (2014, in review). From land use to land cover: Restoring the afforestation signal in a coupled integrated assessment - earth system model and the implications for CMIP5 RCP simulations. *Biogeosciences Discussions (available soon)*.

Bond-Lamberty et al. (2014, in review). Coupling earth system and integrated assessment models: The problem of steady state. *Geoscientific Model Development Discussions*, doi:10.5194/gmdd-7-1499-2014.

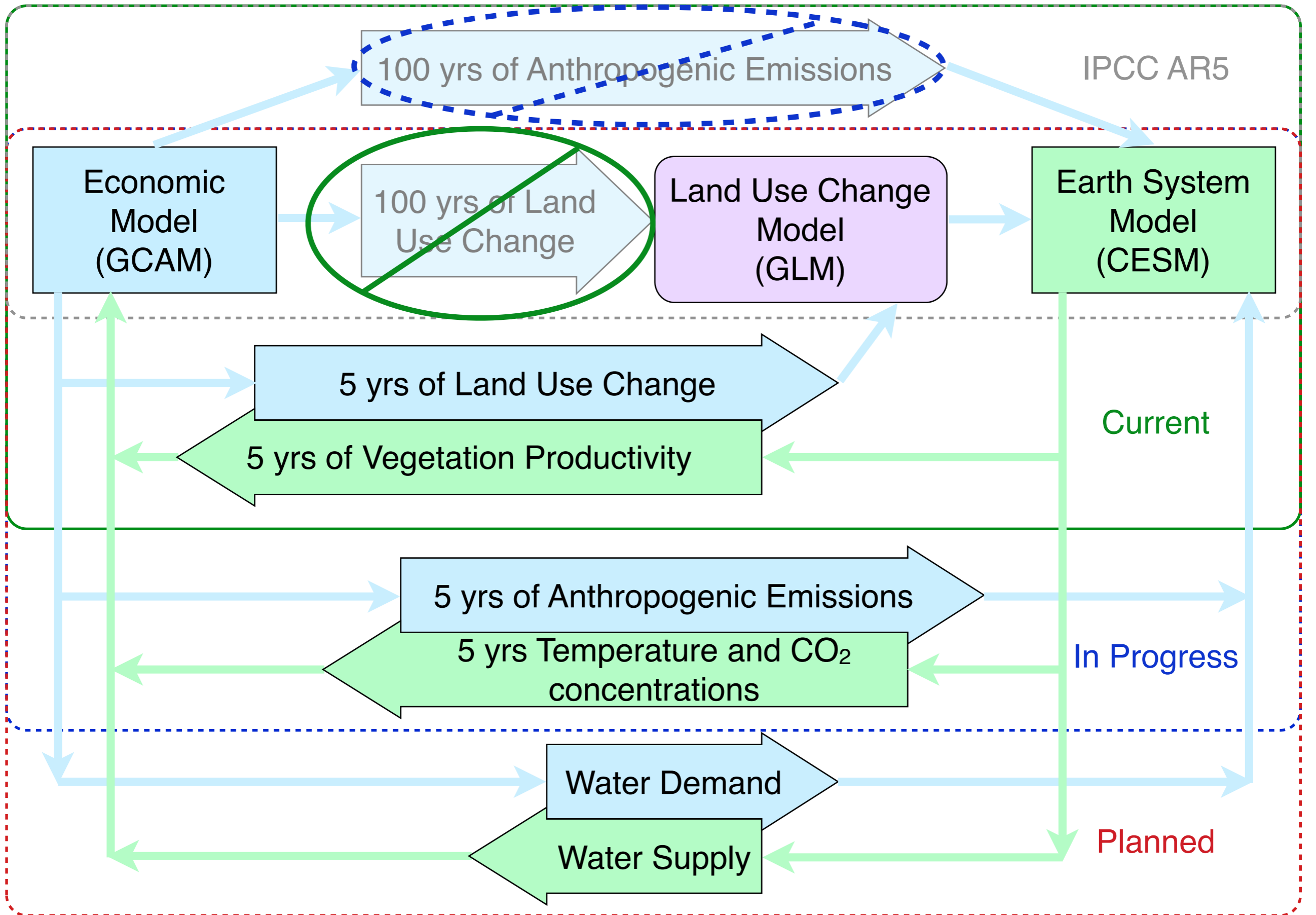


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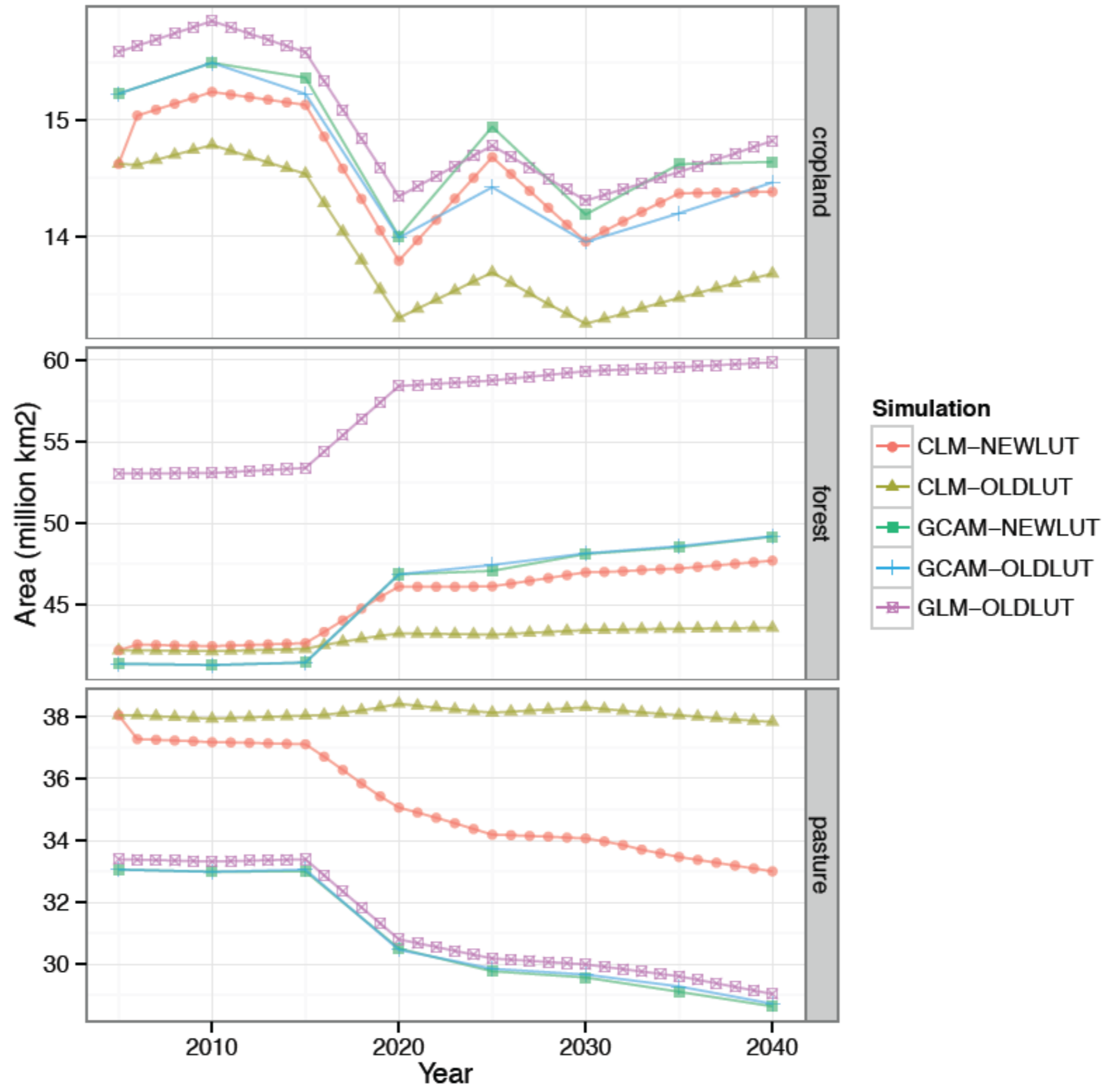


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### Absolute area



# In the context of the integrated Earth System Model (iESM)

## To what extent can we restore the RCP4.5 afforestation solely within CLM/CESM?

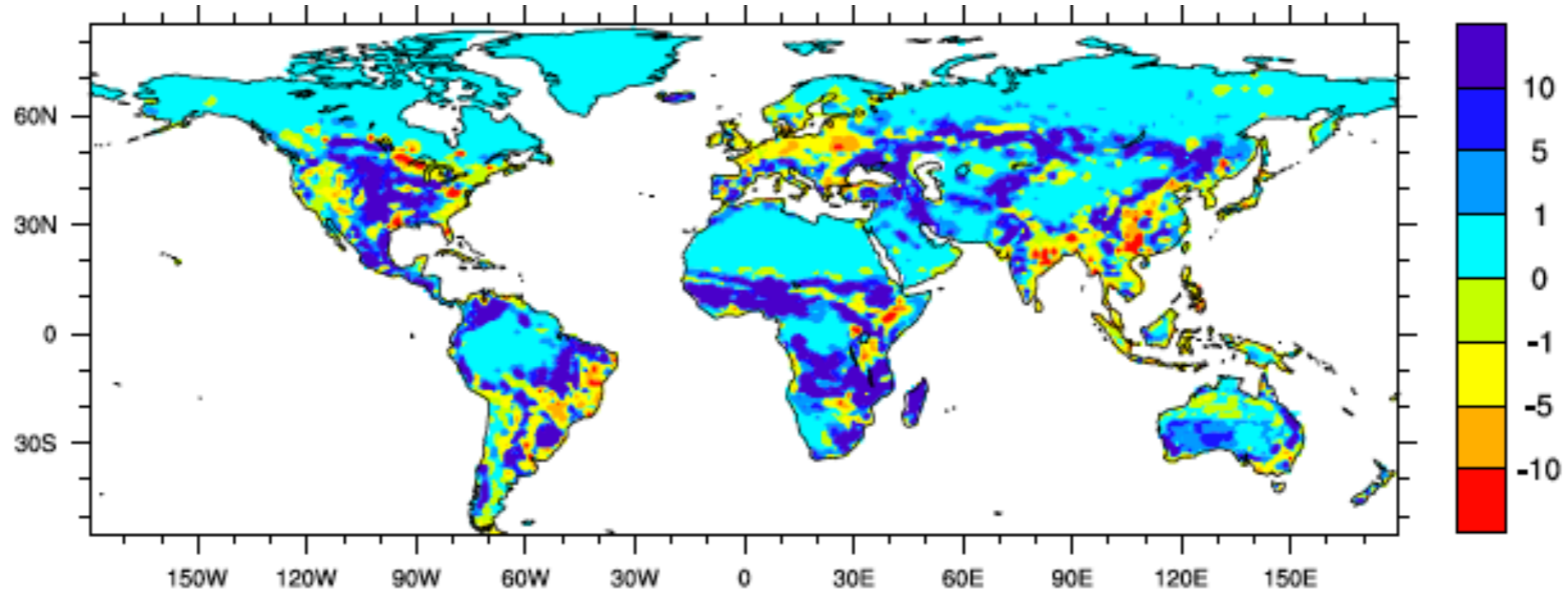


```
updateannualanduse.c:1825  //
// setavailtreefrac = 1 is proportional removal to available potential
// setavailtreefrac = 0 is add trees first (maximize forest)
// Ranges from 1 to 2 for minimizing forest (maximize herbaceous+bare)
// setavailtreefrac = 1 is proportional removal to available potential
// setavailtreefrac = 2 is add herb-bare first (minimize forest)
3205 if (setavailtreefrac >= 0.0 && setavailtreefrac <= 1.0) {
3206   availtreefracremain = min(availtreefracremain, setavailtreefrac + (propavailtreefracremain -
3207     min(availtreefracremain));
3208 } else if (setavailtreefrac <= 2.0) {
3209   setavailtreefracremain = setavailtreefrac - 1.0;
3210   availtreefracremain = propavailtreefracremain + setavailtreefrac + (max(availtreefracremain -
3211     propavailtreefracremain));
3212 } else {
3213   printf("Error: setavailtreefrac %f not within input range of 0 to 2 in sethurrytree!\n", setavailtreefrac);
3214 }
3215
3216 if (availpotvegherbfracpftsum > 0.0) {
3217   availherbfracremain =
3218     (1.0 - availtreefracremain) + availpotvegtreepftsum / availpotvegherbfracpftsum -
3219     (addpftsum / availpotvegherbfracpftsum) + 1.0;
3220 }
3221 else {
3222   availherbfracremain = 1.0;
3223 }
3224
3225 // ensure that the fractions are between 0.0 and 1.0
3226 if (availherbfracremain < 0.0) { availherbfracremain = 0.0; }
3227 if (availherbfracremain > 1.0) { availherbfracremain = 1.0; }
3228 if (availtreefracremain < 0.0) { availtreefracremain = 0.0; }
3229 if (availtreefracremain > 1.0) { availtreefracremain = 1.0; }
3230
3231 printf("availtreefracremain: %f\n", availtreefracremain);
3232 printf("availherbfracremain: %f\n", availherbfracremain);
3233
3234 // add tree pfts by potential proportions
3235 // if there is no potential tree veg then these authorpftvals do not change
3236 outavailpotvegtreepftsum = availpotvegtreepftsum;
3237 if (potvegtreepftsum > 0.0) {
3238   for (outpft = 0; outpft <= 0; outpft++) {
3239     authorpftval[outpft][outgrid] =
3240       round(outpftval[outpft][outgrid] * (1.0 - availtreefracremain)) / potvegtreepftsum;
3241     outavailpotvegtreepftsum = outavailpotvegtreepftsum -
3242       round(inpotvegtreepftsum[outpft][outgrid] *
3243         (availpotvegtreepftsum + (1.0 - availtreefracremain)) / potvegtreepftsum);
3244   }
3245 }
3246
3247 // add herbaceous+bare by potential proportions
3248 // if there is no potential herb-bare veg then these authorpftvals do not change
3249 // the bare soil is changed above if needed
3250 outavailpotvegherbfracpftsum = availpotvegherbfracpftsum;
3251 if ((potvegherbfracpftsum + inpotvegtreepftsum) > 0.0) {
3252   for (outpft = 0; outpft <= 0; outpft++) {
3253     authorpftval[outpft][outgrid] = round(outpftval[outpft][outgrid] + inpotvegtreepftsum[outpft][outgrid] *
3254       (potvegherbfracpftsum + inpotvegtreepftsum) /
3255       (availpotvegherbfracpftsum + (1.0 - availherbfracremain)) /
3256       (potvegherbfracpftsum + inpotvegtreepftsum));
3257     outavailpotvegherbfracpftsum = outavailpotvegherbfracpftsum -
3258       round(inpotvegtreepftsum[outpft][outgrid] *
3259         (availpotvegherbfracpftsum + (1.0 - availherbfracremain)) /
3260         (potvegherbfracpftsum + inpotvegtreepftsum));
3261     authorpftval[0][outgrid] = round(authorpftval[0][outgrid] + inpotvegtreepftsum[0][outgrid] *
3262       (potvegherbfracpftsum + inpotvegtreepftsum) /
3263       (potvegherbfracpftsum + inpotvegtreepftsum));
3264     outavailpotvegherbfracpftsum = outavailpotvegherbfracpftsum -
3265       round(inpotvegtreepftsum[0][outgrid] *
3266         (availpotvegherbfracpftsum + (1.0 - availherbfracremain)) /
3267         (potvegherbfracpftsum + inpotvegtreepftsum));
3268   }
3269 }
3270
3271 printf("outavailpotvegtreepftsum: %f\n", outavailpotvegtreepftsum);
3272 printf("outavailpotvegherbfracpftsum: %f\n", outavailpotvegherbfracpftsum);
3273 // check forest maximization
3274 // this check takes into account rounding error up to 1 unit (percent) of veg land unit
3275 if (setavailtreefrac == 0.0 && addpftsum == availpotvegtreepftsum &&
3276     (outavailpotvegtreepftsum < -1.0 || outavailpotvegtreepftsum > 1.0)) {
```

## How does restored afforestation affect the carbon cycle and climate?

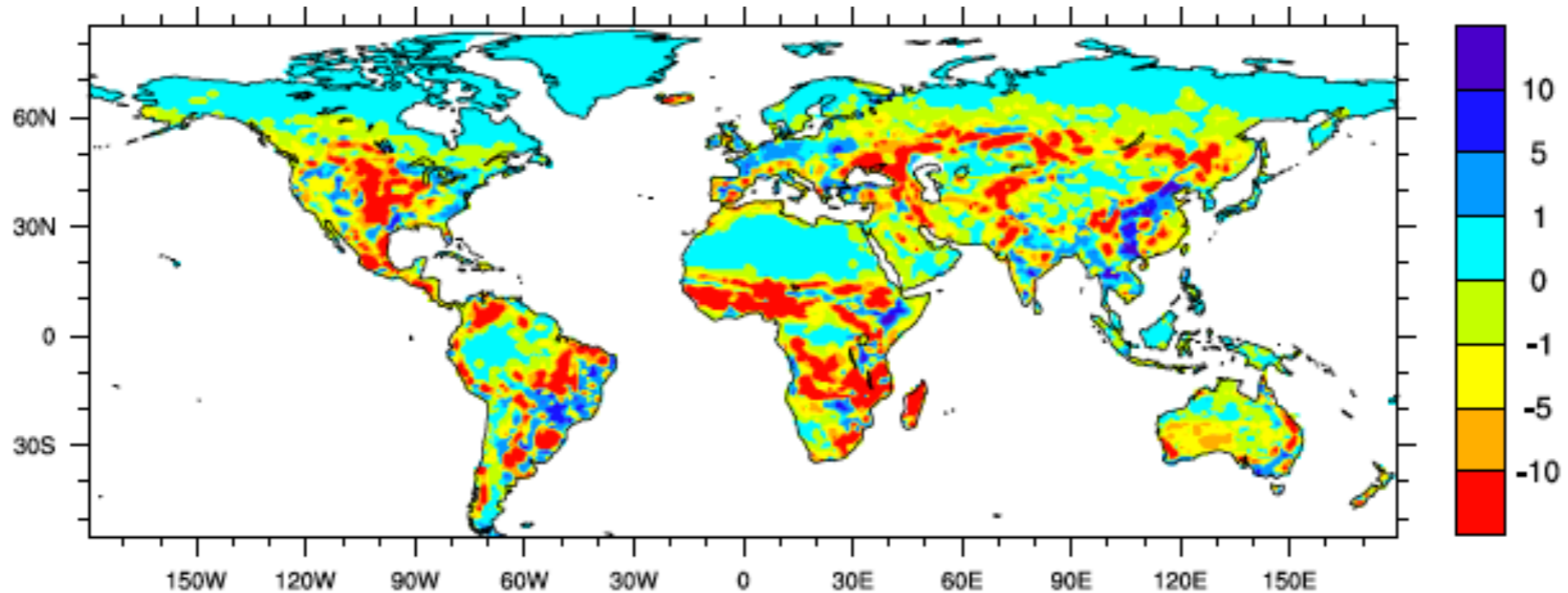
# Most new trees replace shrubs and grass

## Difference in tree PFT area (2040)



NEWLUT -  
OLDLUT

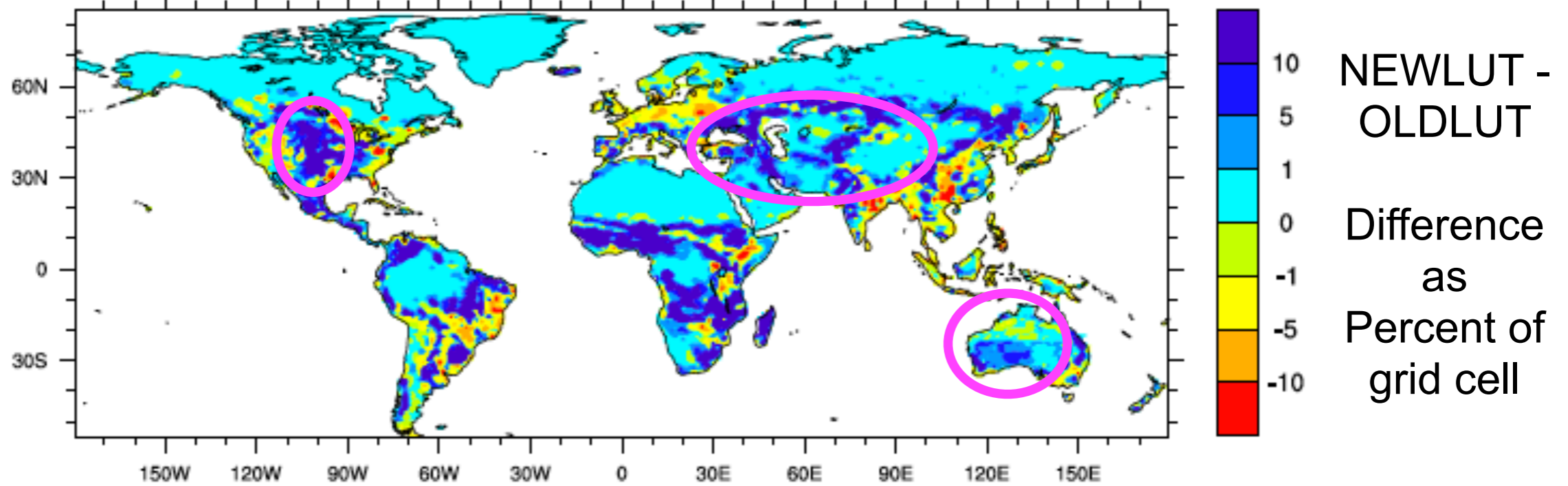
## Difference in shrub and grass PFT area (2040)



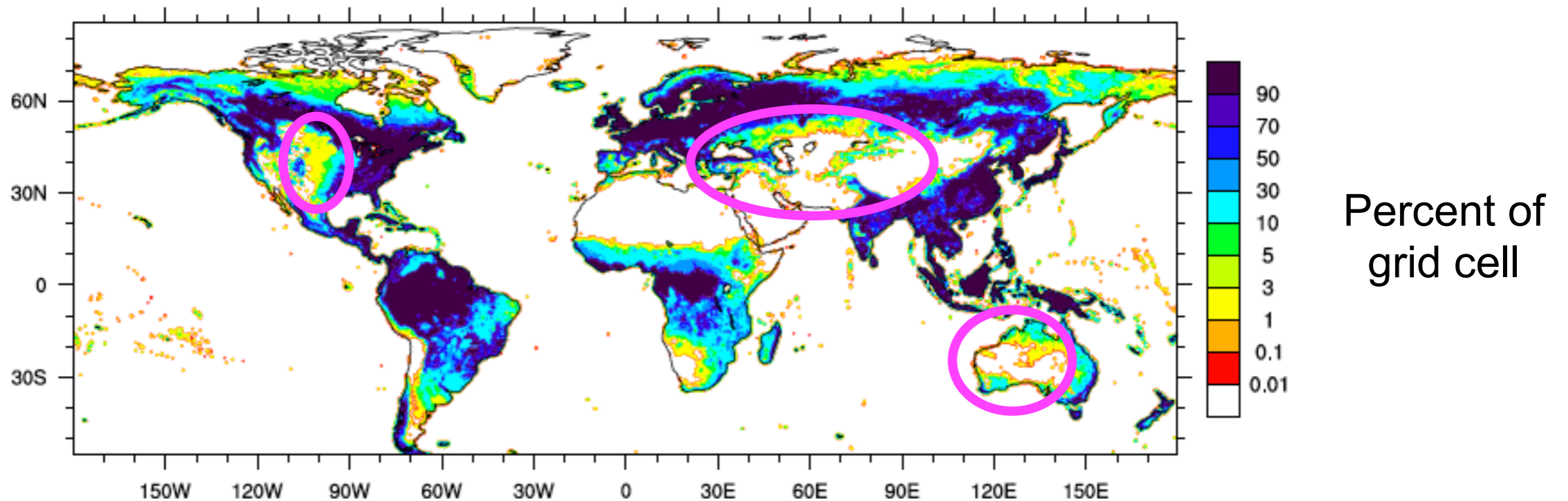
Difference  
as  
Percent of  
grid cell

# Not always coincident with potential forest

## Difference in tree PFT area (2040)

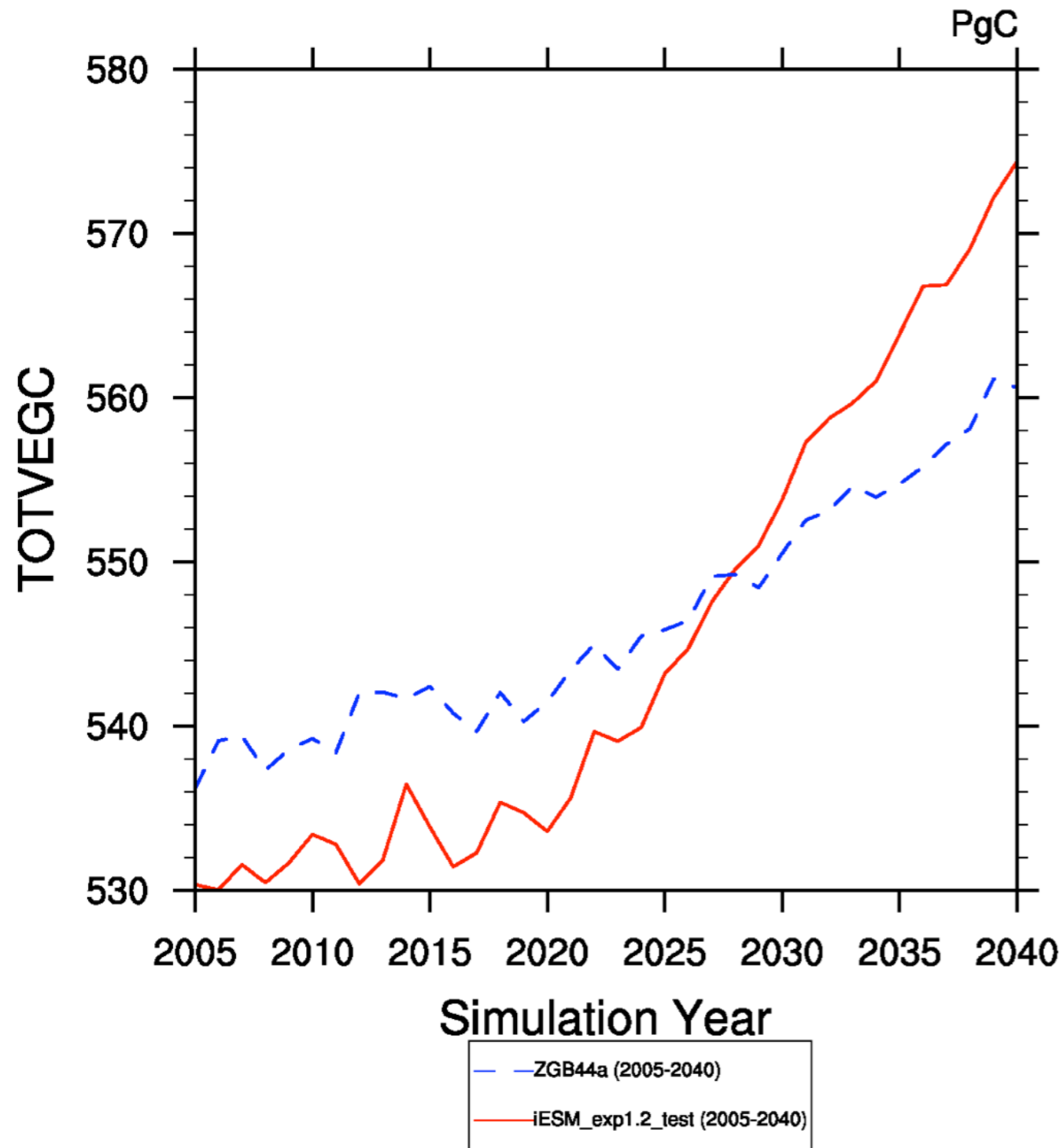


## Potential forest area



# iESM veg carbon and atmospheric CO<sub>2</sub>

total vegetation C, excluding cpool



CO2 concentration

