Understanding the importance of scale in an Integrated Assessment Model: Insights from multi-scale agricultural simulations with GCAM

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INTRODUCTION

Recent model developments enable the use of higher resolution representation of sectors and geographic regions in Integrated Assessment Models (IAMs). This opens up the possibility of focused regional and sectoral studies nested within a global integrated framework, providing the advantage of maintaining the global scope of analysis. Such information can then be downscaled to even higher resolutions for use in further scientific analysis or decision support applications.

Higher resolution nested simulations involve cost s - data assembly and reconciliation, model re-calibration and increased model run time. Here we test multiple of spatial resolution of the Global Change Assessment Model (GCAM) agriculture and land use sector for the US Midwest to better understand the tradeoffs of going to higher spatial resolutions and to inform selection of appropriate spatial scale of analysis for agriculture and land use studies in integrated assessment models.

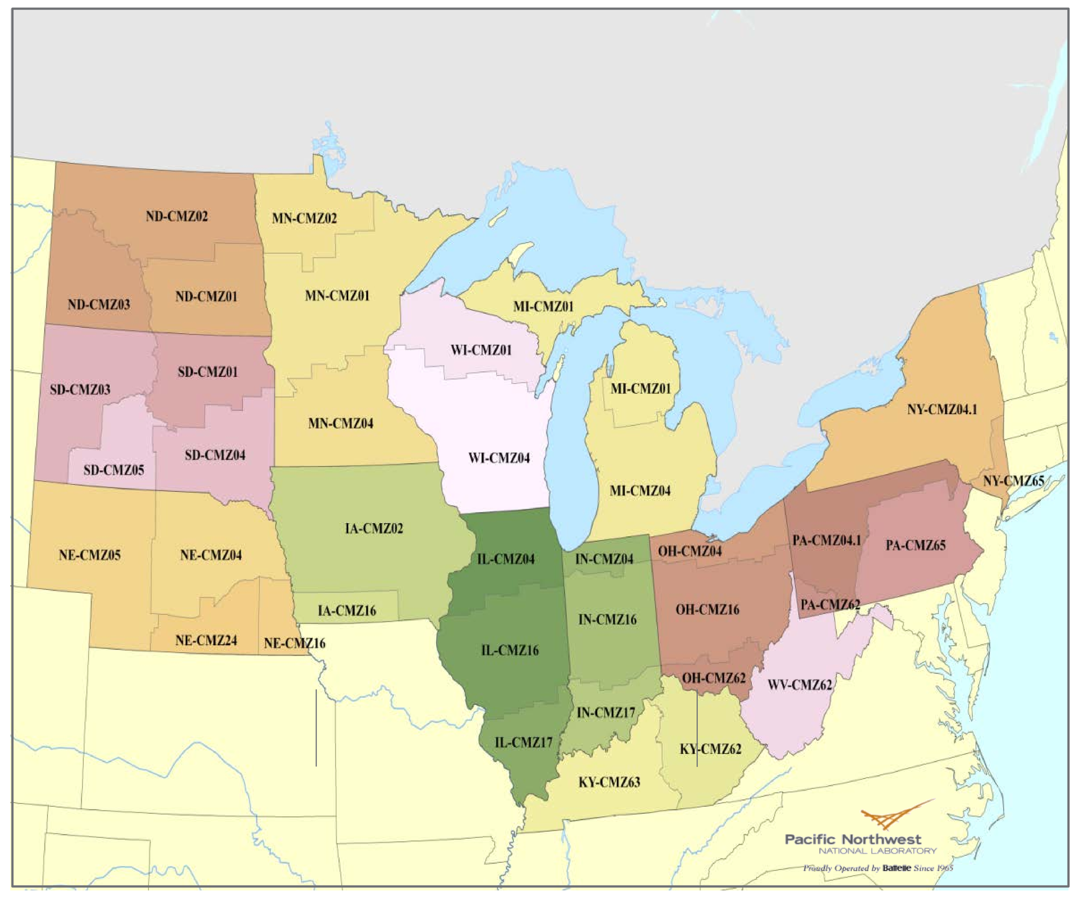


Figure 1: 14 state subregion nested in the global GCAM for this study. Four different aggregations of modeling units were tested:

- area as 1 region (R_1),
- area divided by USDA defined Crop Management Zones (CMZ) (R_12);
- area divided by state (R_14);
- area divided by combination of State and CMZ (boundaries shown in figure) (R_37).

METHODS

The standard GCAM spatial resolution includes 10 subregions in the USA, several of which overlap with the 14 state region of interest in this study. The 14 state US Midwest region was selected due to previous work that established a highly detailed agricultural input data set for GCAM (Thomson et al., 2013). By aggregating the same input data to different modeling unit definitions, we are able to isolate the consequences of scale. By selecting a small area to conduct the experiment, we are able to explore model behavior. These results will be used in part to design a series of simulations with global-scale spatial resolution scenarios.

Data were aggregated to the four different regional definitions (Table 1) for the Midwest region (Figure 1). We use a common set of data inputs and aggregate these to 1, 12 (crop management zone (CMZ) boundaries), 14 (state boundaries) and 37 (combination of state boundary and crop management zone) region, respectively. GCAM was then re-calibrated for a global simulation using these four different input data sets, and run forward to 2100 under a reference case and a climate mitigation pathway that stabilizes radiative forcing at 4.5 W/m2 (MP4.5). GCAM simulates the MP4.5 with a Universal Carbon Tax that places an economic value on all carbon stocks and emissions.

GCAM simulates future land cover and agricultural activity while fully coupled to the energy system and tied to future human population and income, which drive demands for food, energy and other products. For full documentation see Wise et al. (2014) and the GCAM Wiki (http://wiki.umd.edu/gcam). The results were aggregated to a smaller set of land use categories for presentation (Table 2).

Table 1: Simulations of global GCAM for this study with different spatial aggregation

Case	Regional definition	Pathway	GCAM domain	Total GCAM subregions
R_1_ref	One region	Reference	Global	151
R_12_ref	Aggregated by CMZ	Reference	Global	162
R_14_ref	Aggregated by state	Reference	Global	164
R_37_ref	States separated by CMZ	Reference	Global	187
R_1_4.5	One region	MP4.5	Global	151
R_12_4.5	Aggregated by CMZ	MP4.5	Global	162
R_14_4.5	Aggregated by state	MP4.5	Global	164
R_37_4.5	States separated by CMZ	MP4.5	Global	187

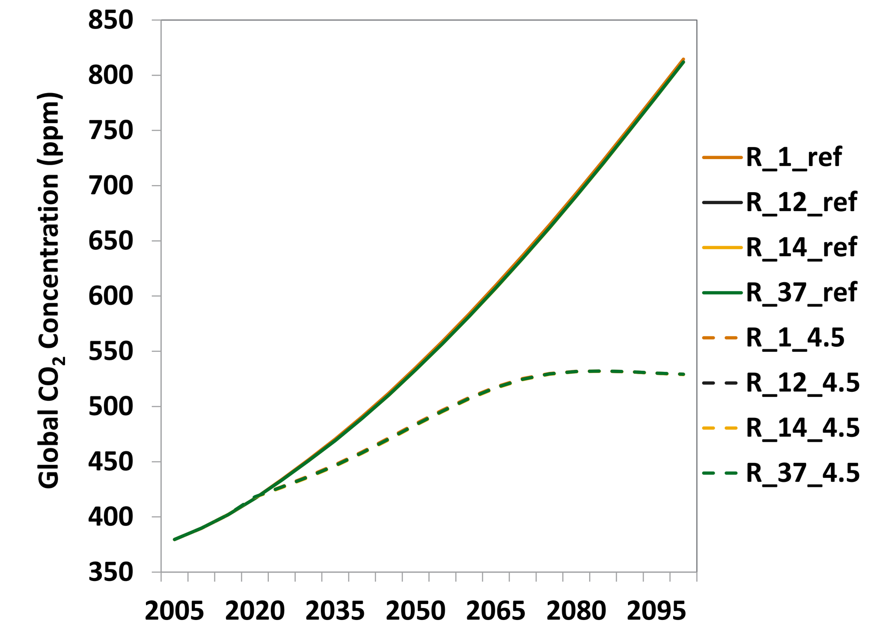
Table 2: Land use categories represented

GCAM LUT	Aggregated LUT
Forest	Non-agricultural
Grassland	Non-agricultural
OtherArableLand	Other crops
Pasture	Livestock
RockIceDesert	Non-agricultural
Shrubland	Non-agricultural
Tundra	Non-agricultural
UrbanLand	Non-agricultural
biomass	Bioenergy
Corn	Corn
FodderGrass	Livestock
FodderHerb	Livestock
MiscCrop	Other crops
OilCrop	Oil crops
OtherGrain	Other crops
Root_Tuber	Other crops
SugarCrop	Other crops
Wheat	Wheat

RESULTS

Global: At the global scale, the influence of the different modeling unit definition for this subregion is noticeable but not large. The global CO_2 concentration (Figure 2) in the reference case is higher by ~2 ppm in 2100 in the R_1 case compared to the other three modeling unit definitions. This is a result of higher emissions from land use change (Figure 3) both within the subregion and in the rest of the world (data not shown). While under the MP4.5 case, CO_2 emissions from land use are also higher, this is compensated for by mitigation elsewhere in the energy sector to maintain the mitigation requirement of the scenario. However, the price of carbon is slightly different as a result of the different effort required to achieve the same level of mitigation.

Figure 2: Global CO_2 concentration



Regional - Reference: In the reference case change in land area is driven by changing food demands due to population and income. Bioenergy emerges as an energy supply technology in the model that competes with other energy sources. The emergence of dedicated bioenergy crops is apparent in all cases (Figure 4) primarily displacing non-agricultural land and land in pasture for livestock.

Regional-4.5 Mitigation Policy: in the MP4.5 case, land use change is influenced by a carbon price that values terrestrial C, and therefore changes the relative profit rates of different land uses, compared to the reference case. In most cases, the changes in the reference scenario are intensified in going from reference to 4.5. In addition to the emergence of bioenergy, the MP4.5 cases also show an increase in land area for corn and other food crops and an intensification of animal production, illustrated by reductions in pasture land (livestock). These results are consistent with Thomson et al. (2013), who found that food crops in this region are more highly profitable than alternative land uses under mitigation policies.

Figure 4: Aggregate land use change over the 14 state subregion for all simulations in 2050 illustrating the difference between modeling unit aggregations.

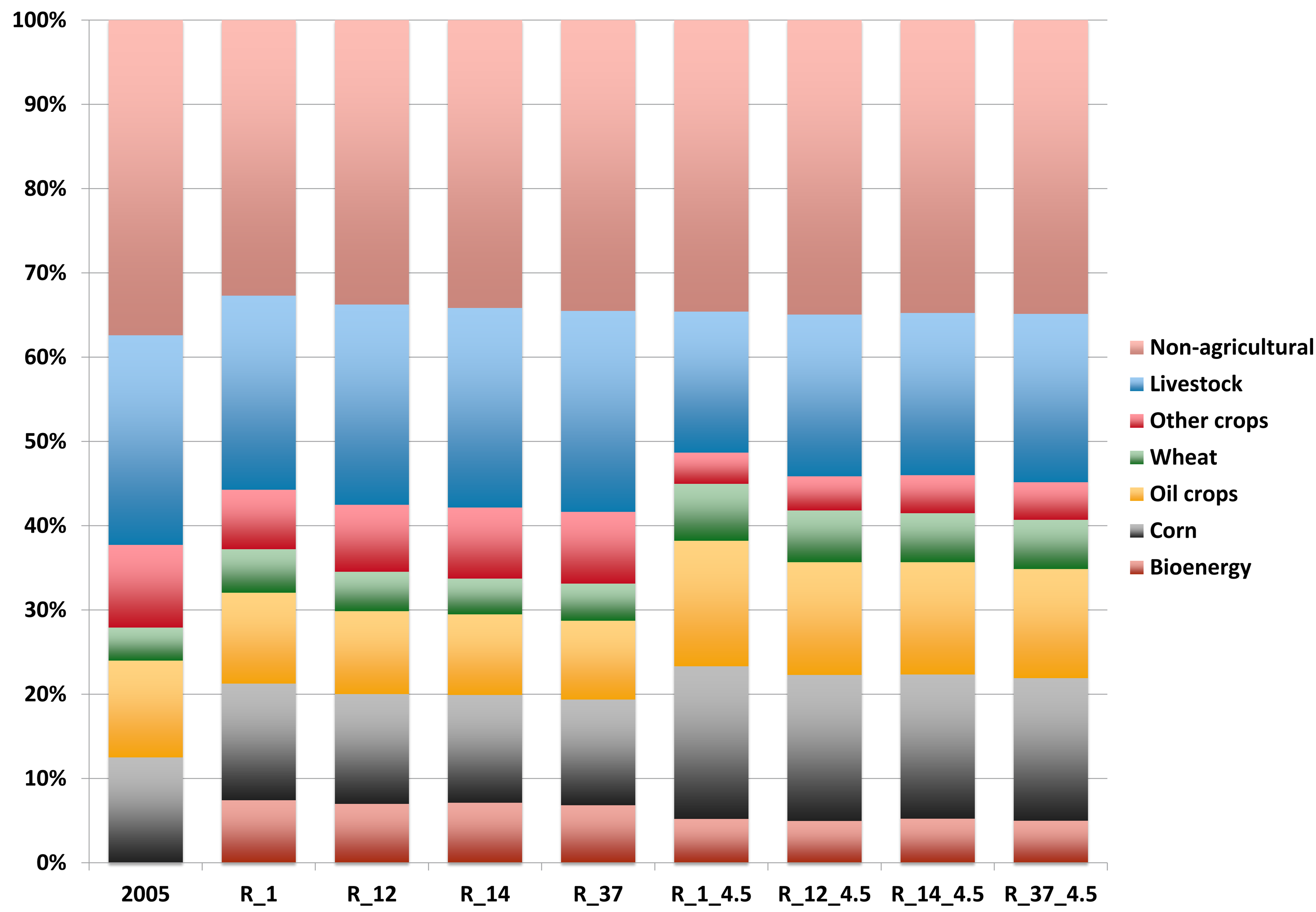


Figure 3: Global land use change emissions

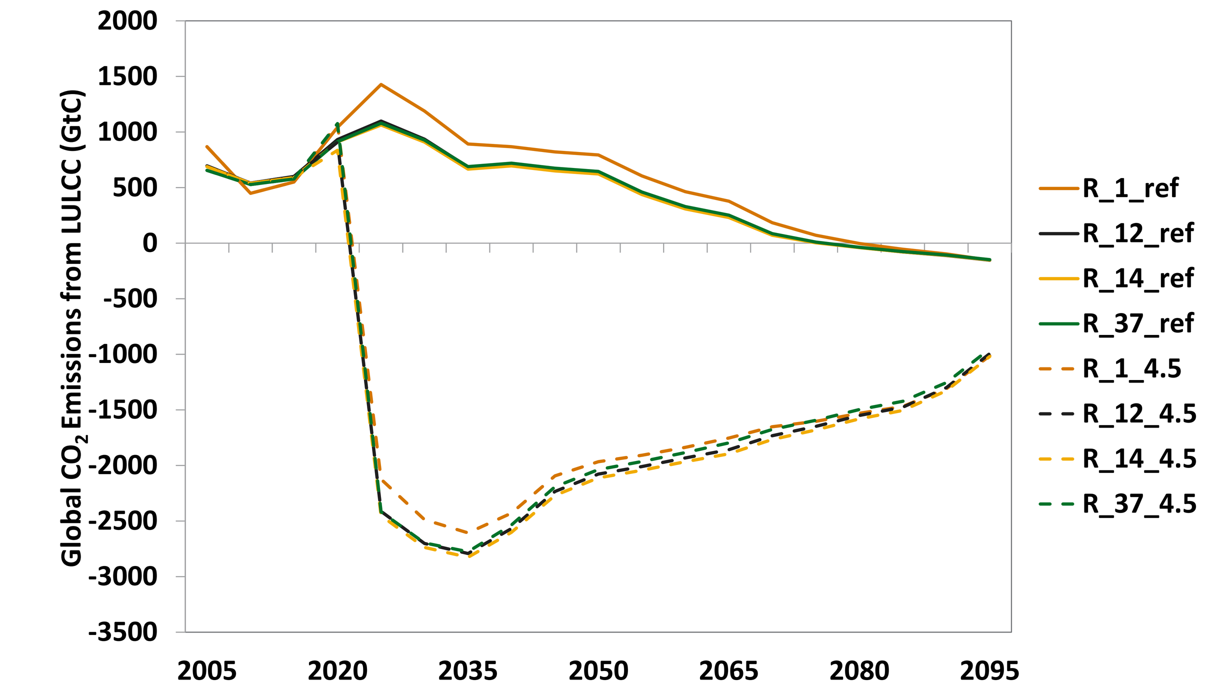
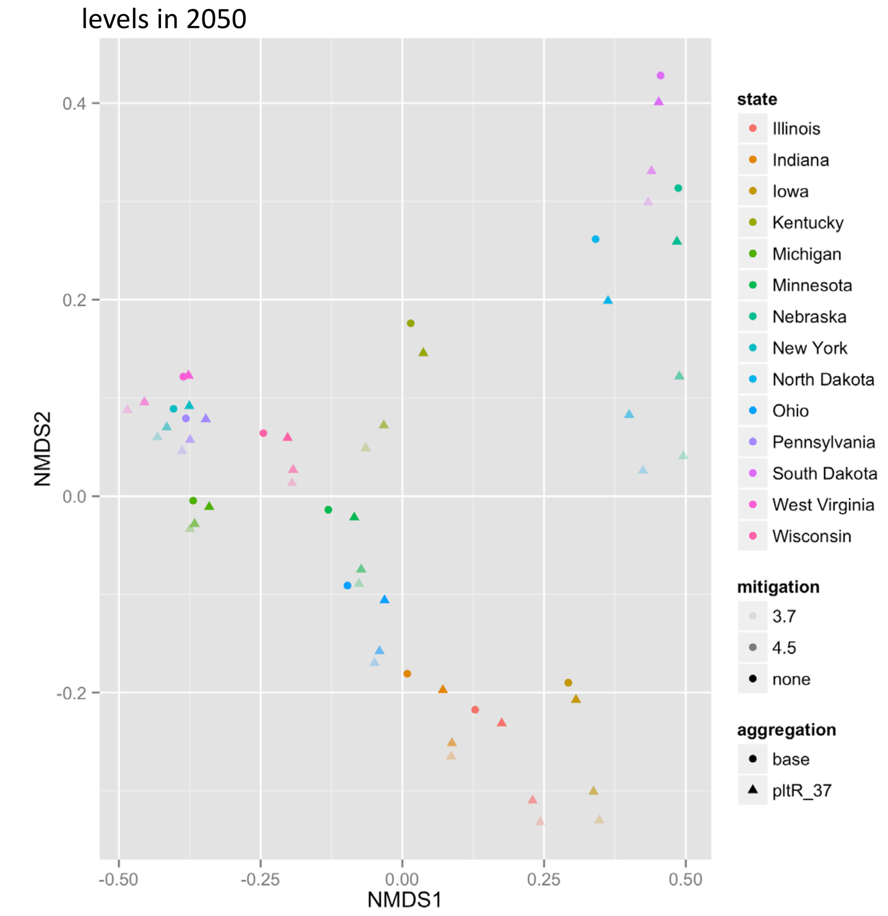


Figure 5: NMDS analysis of aggregate LUC at the state level for R_14 (base) and R_37 aggregations at different mitigation levels in 2050



Results by state: A multivariate analysis (non-metric multidimensional scaling, NMDS) was applied at the state level to explore how individual states change and how that is impacted by the R_14 versus R_37 spatial aggregations, and by different climate mitigation levels (Figure 5).

States with similar land use and change will be located close to one another in the figure. For example, states with large corn and soy production (IA, IL, IN) are grouped together whereas states with large non-agricultural land proportions are likewise close (NY, WV, PA, WI, MI).

In most cases, the changes from 2005-2050 in the reference scenario are intensified in going from reference to a mitigation policy. The exceptions are the states with high shares of unmanaged lands, where the in the reference scenario the shares of non-agricultural land decrease from 2005 to 2050, a trend which is reversed in the mitigation scenarios.

The patterns of land use change in these scenarios from 2005 to 2050 contain some elements that are generic to all subregions in the pilot region, and others that are specific to individual states and/or CMZs. For example, all states show an increase in bioenergy grass crop production which on its own will tend to move the points in similar directions in the graph.

Emissions mitigation policies cause regions to specialize further in their primary land use types — whether corn/soy, wheat, or non-agricultural land— which tends to cause inter-state divergence in the land use patterns over time.

CONCLUSIONS

We find that all four spatial modeling unit aggregations produce reasonable results, but that the model solution is affected by the modeling unit definition chosen. The clearest difference is between R_1 and the other three cases, leading to the conclusion that higher resolution is important in this region to characterize the diversity of land uses. The boundaries that better isolate where crop yields are high and where they are low is better for modeling agricultural systems than an aggregate boundary that averages the highs and lows across the entire region. This also indicates that higher spatial resolution is important for studies where climate change impacts on crop yields are considered (e.g. Kyle et al., 2014).However, there was no significant difference between the use of CMZs, an agriculturally defined category of land use, and states, a politically defined category (R_12 and R_14).

We find that the spatial aggregation does not alter the basic relationship between the reference and mitigation policy (MP4.5) cases. However the different spatial scale does result in differences in the relative future extent of food and bioenergy crops within the study region and within individual states. We plan to extend this analysis further by downscaling future land cover to a high resolution grid and evaluating the importance of the different regional aggregation of model simulation for the final, spatially explicit, model product (West et al., 2014).

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