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Harmonisation of global land-use scenarios for the period 1500–2100 for IPCC-AR5

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The evidence is now overwhelming that human activity has significantly altered basic element cycles (*e.g.* of carbon and nitrogen), the water cycle, and the land surface (*e.g.* vegetation cover, albedo) at regional, continental, and planetary scales, and that these alterations are influencing the regional and global environment, including the Earth's climate system.

During the last 300 years, 42–68% of the land surface has changed because of land-use activities (crop, pasture, and wood harvest), some of it multiple times [1]. Agricultural land now covers more than a third of the land surface [1,2], and globally there are 10–44 · 10^6 km^2 of land that is recovering from previous human land-use activities ("secondary" land) [1].

These land-use changes are estimated to have added carbon to the atmosphere, altered the surface albedo, surface aerodynamic roughness, and rooting depth of

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vegetation, with resulting changes in regional and global water, carbon, and climate. Looking ahead, population and the demand for energy, food, fibre, and water are expected to increase further, placing even greater pressure on the Earth system.

In preparation for the fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the international community is developing new advanced Earth System Models (ESM) to address the combined effects of human activities (*e.g.* land use and fossil fuel emissions) on the carbon-climate system.

In addition, four Representative Concentration Pathways (RCP) scenarios of the future (2005–2100) are being provided by four Integrated Assessment Model (IAM) teams to be used as input to the ESMs for future climate projections). The RCPs represent three mitigation pathways (two stabilisation and one overshoot and decline) and one no-policy pathway that continues to increase radiative forcing beyond 2100.

The diversity of requirements and approaches among ESMs and IAMs for tracking land-use changes (past, present, and future) is significant. Moreover, IAM future projections must smoothly transition from the end of historical reconstructions. For these reasons treating land use comprehensively and consistently among these communities in the IPCC exercise (Fig. 1) is an important challenge.

As part of an international working group, we have been working to meet these challenges by developing a "harmonised" set of land-use change scenarios. Each harmonised scenario smoothly connects spatially gridded historical reconstructions of land use with future projections in a format required by the ESMs.

Previously, we created the Global Land-use Model (GLM) that produced estimates of 1° x 1° fractional land-use patterns (*e.g.* crop, pasture, secondary) and underlying land-use transitions annually 1700–2000 [1].

Land-use transitions describe the annual changes in land use and are important because changes such as harvesting trees and establishing or abandoning agricultural land often directly alter land-surface characteristics that, in turn, affect energy, water, and carbon exchanges between the land surface and the atmosphere. Resulting land-use data have been successfully used as input to a new global dynamic land model (LM3V) able to track the consequences of these changes for both the carbon cycle and climate [3].

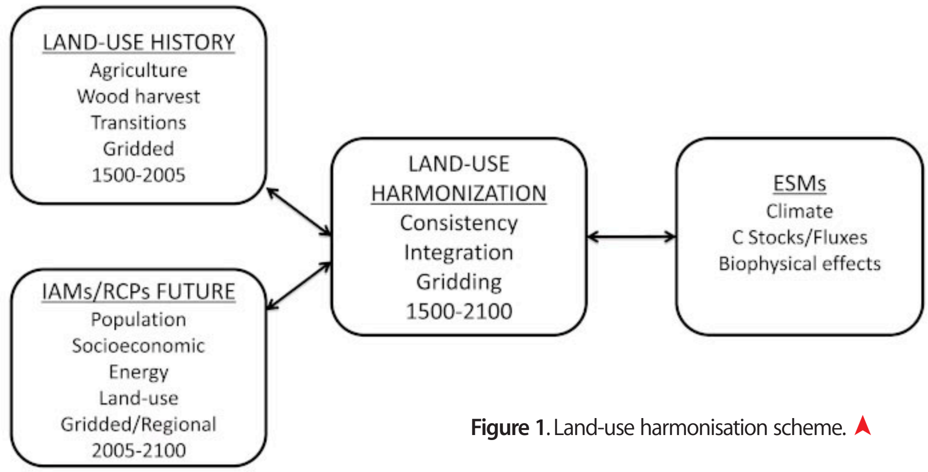
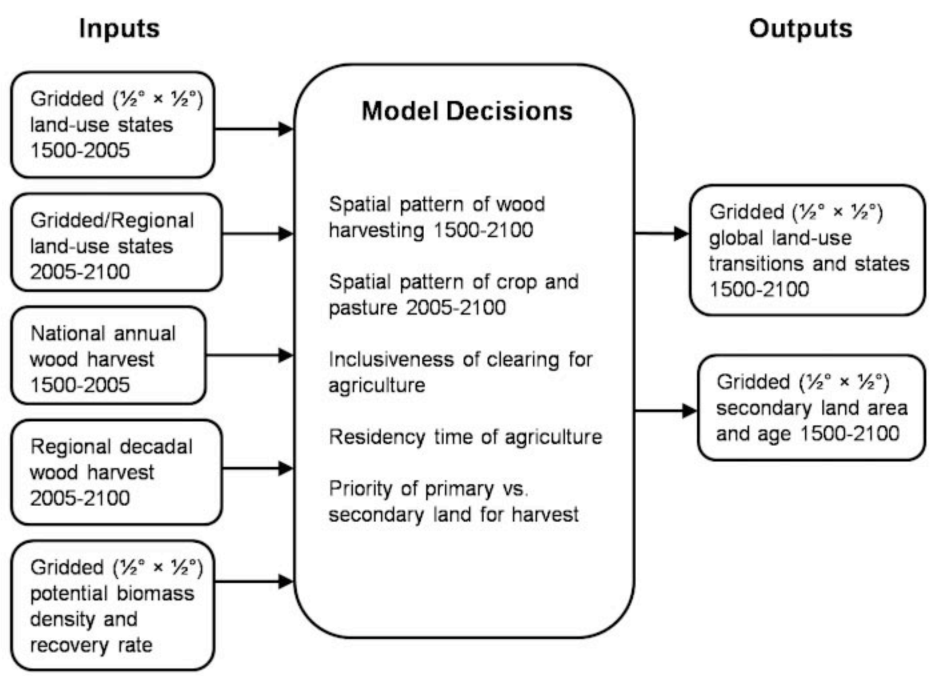


Figure 1. Land-use harmonisation scheme.

Figure 2. Flow diagram of inputs, outputs, and model decisions for the global land-use model (GLM) used in harmonisation.



Our new land-use harmonisation strategy builds upon the GLM framework by computing enhanced estimates of land-use patterns and underlying land-use transitions annually for the time period 1500–2100 at 0.5° x 0.5° resolution (Fig. 2). Inputs include new gridded historical maps of crop and pasture data from HYDE 3.0 1500–2005 [2], updated estimates of historical national wood harvest and of shifting cultivation, and future information on crop, pasture, and wood harvest from the IAMs implementations of the RCPs for the period 2005–2100.

Our computational method integrates these multiple data sources while minimising differences at the transition between the historical reconstruction ending conditions and IAM initial conditions, and working to preserve the future changes depicted by the IAMs at the grid level.

Fig. 3 illustrates preliminary harmonisation time series results based on one of the IAMs, the IMAGE model, aggregated globally for the period 1900–2100.

The four solid lines in Fig. 3 represent global time series (1900–2100) for cropland, pasture, primary land (natural vegetation with no prior land-use history) and secondary land. The dashed lines represent global cropland and pasture time-series (2005–2100) from the IMAGE model. The figure shows that the transition from past to fu-

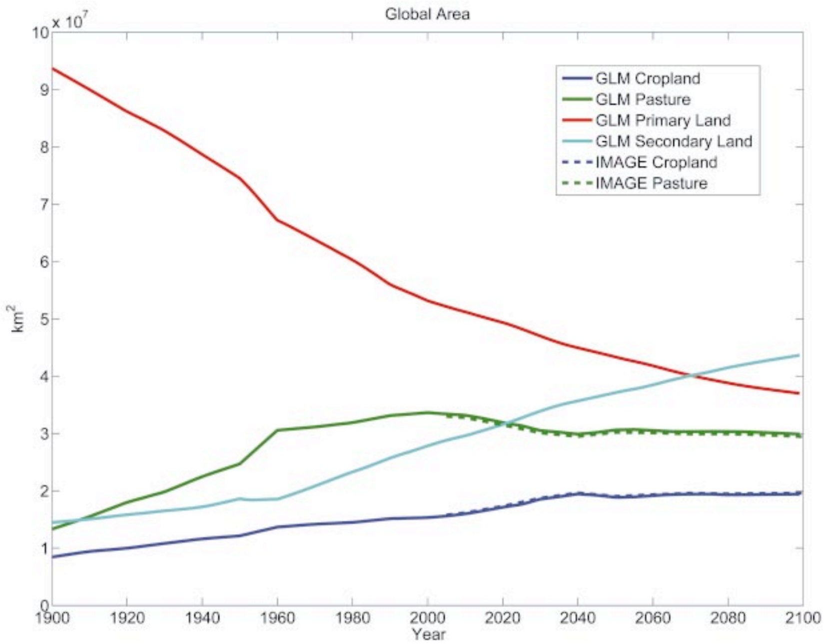


Figure 3. Time series of global area of cropland, pasture, primary land, and secondary land from the output of global land-use models (GLM) compared with IMAGE model (one of the IAMs) inputs. A major goal of our harmonisation was to re-grid the IAM crop and pasture inputs by applying IAM decadal changes to the historical reconstructions to ensure a smooth transition from past to future in 2005. This figure shows that the global harmonised land-use data (output from GLM) does indeed transition smoothly from past to future in 2005 and faithfully preserves global land-use changes in the IAM land-use data (IMAGE cropland and pasture data). Primary and secondary land were computed as part of the GLM. The algorithms used there are one of the key contributions of our work.

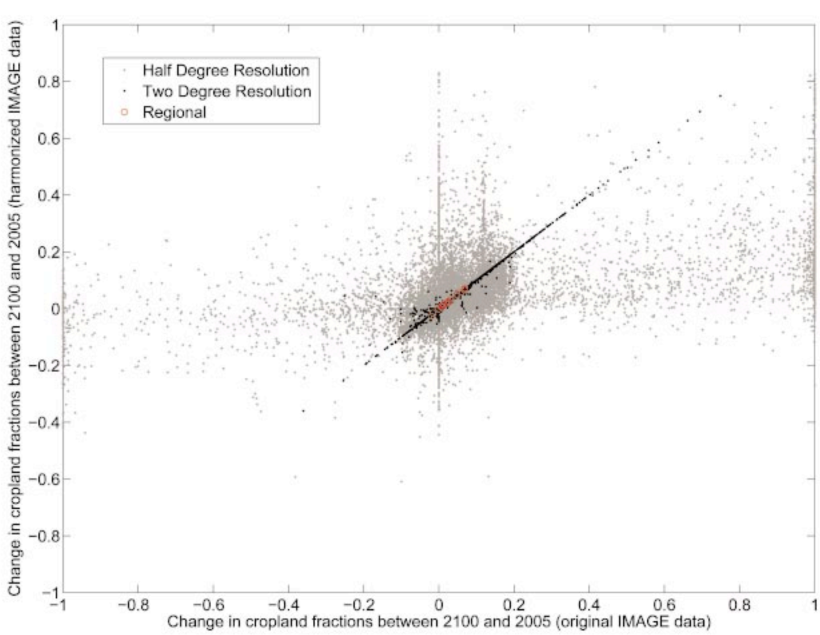


Figure 4. Scatter plot of gridded cropland changes in IMAGE (one of the IAMs) data compared with cropland changes in the harmonised dataset (2005 to 2100), at 0.5-degree (grey, $n \sim 70{,}000$), 2-degree (black, $n \sim 5000$), and regional (red, $n = 24$) resolution. Our harmonisation scheme attempts to preserve spatial patterns of IAM decadal crop and pasture changes while ensuring a smooth transition from past to future in 2005—this figure shows that although at 0.5-degree spatial resolution the land-use changes computed from the harmonisation strategy do not preserve those provided by the IAMs, at 2-degree and regional spatial resolutions the land-use changes are preserved well.

ture is smooth for all land-use categories (cropland, pasture, primary, and secondary) and close to the aggregated results from the IMAGE model (for cropland and pasture). It also shows that the harmonised land-use projections faithfully preserve future crop and pasture land-use changes computed by the IAMs.

Fig. 4 summarises corresponding gridded results, and indicates that the harmonisation strategy does a reasonable job of also preserving IMAGE gridded changes, particularly when aggregated to 2° x 2° resolution, and at regional scales.

Understanding the effects of human activities on the Earth system requires that the best technical expertise and data on land use be incorporated into the best climate models. Our approach of harmonising the treatment of land use between ESMs and IAMs represents a major advance that will facilitate fuller and more consistent treatments of how both land use and land-use change influence the Earth system, including the effects of CO_2 emissions, and corresponding gridded land-surface changes that potentially have biogeophysical effects.

Preliminary products from this activity are currently available; final products will include urban lands, and be finalised using data from all four IAMs later in 2009. Future efforts are necessary to fully implement these products and to integrate ESM and IAM modelling communities even more tightly for future studies of the coupled human-climate system. ■

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