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Horizon 2020 Societal challenge 5: Climate action, environment, resource efficiency and raw materials

VERIFY

Observation-based system for monitoring and verification of greenhouse gases

GA number 776810, RIA

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Lead beneficiary:	LMU Munich
Responsible	LMU Munich
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Internal reviewer:	Philippe Peylin (CEA-LSCE)

1. Changes with respect to the DoA

None

2. Dissemination and uptake

The deliverable provides a documentation of the current published estimates of the net land use change flux simulated by BLUE model (Bookkeeping of Land Use Emissions model). This is of use to the other modelers, as it describes the content, format and first-order estimates of the final BLUE dataset that will be used for evaluation of process-based models, providing prior fluxes to the inversions and for splitting the net land use change into processes.

3. Short Summary of results (<250 words)

The current BLUE net land use change flux estimate has been published as part of the global annual carbon budget 2018. It includes the originally published parameter set with biome-specific carbon densities and response functions. The land-use forcing is taken from the Land Use Harmonization, LUH2. The model provides data at annual time steps and 0.25 degree resolution, which can be aggregated to country level. The fast track analysis in this deliverable compares BLUE to another bookkeeping approach (Houghton and Nassikas, 2017), to dynamic global vegetation models (DGVMs), and the land use total emissions reported by FAO. Generally higher emission estimates than FAO can be attributed to different ways of reporting/accounting. Likely artifacts of LUH2 are revealed by BLUE and the DGVMs (emission peak due to change in data source in 1950s, sudden increase in variability in 2000, emissions peaks in individual years and countries). Other differences between BLUE and Houghton and Nassikas stem from differences in assumed carbon densities. Since land use forcing and carbon densities will be updated in VERIFY we foresee an improvement in BLUE estimates in the coming years.

4. Evidence of accomplishment

The deliverable will be submitted as report and the data will be accessible on the VERIFY database.

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Version	**Date**	**Description**	**Author (Organisation)**
V1	2019/05/14	Writing/Formatting/Delivery	Julia Pongratz (LMU Munich)
V2	2019/06/04	Formatting/Delivery on the Participant Portal	Philippe Peylin (CEA-LSCE, Paris)

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1. Introduction

1.1. BLUE model description

Bookkeeping models (Houghton, 1983) calculate land-use change CO_2 emissions and uptake fluxes for transitions between various natural vegetation types and agricultural lands (so far croplands and pastures). The original bookkeeping approach of Houghton (2003) keeps track of the carbon stored in vegetation and soils before and after the land-use change. Carbon gain or loss is based on response curves derived from literature. The response curves describe decay of vegetation and soil carbon, including transfer to product pools of different life-times, as well as carbon uptake due to regrowth of vegetation and consequent re-filling of soil carbon pools. Natural vegetation can generally be distinguished into primary and secondary land. For forests, a primary forest that is cleared cannot recover back to its original carbon density. Instead long-term degradation of primary forest is assumed and represented by lowered standing vegetation and soil carbon stocks in the secondary forests. Apart from land use transitions between different types of vegetation cover, forest management practices in the form of wood harvest volumes are included. Fig. 1 presents an example of carbon dynamics following a suite of land use transitions.

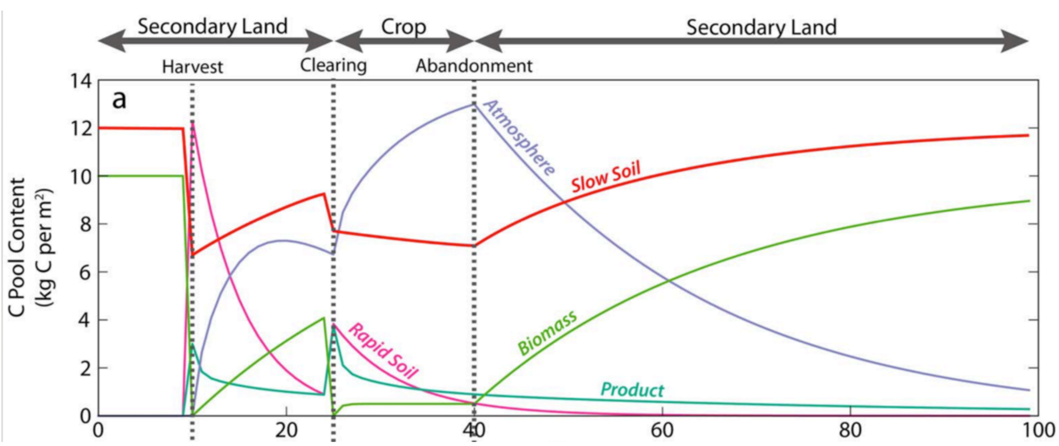

Fig. 1 Model output from an exemplary single-point run. Land cover types and transition events are noted at the figure top. Depicted are carbon pool stocks for vegetation biomass (green curve), slow-process soil pool (red curve), rapid-process soil pool (pink curve), product pool (turquoise curve; for display purposes, all three product pools are combined in one curve), and accumulated emissions to the atmosphere (blue

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curve), plotted over simulation time (Hansis et al., 2015).

Different from dynamic global vegetation models, bookkeeping models ignore changes in environmental conditions (climate, atmospheric CO_2, nitrogen deposition and other environmental factors). Carbon densities at a given point in time are only influenced by the land use history, but not by the preceding changes in the environmental state. Carbon densities are taken from observations in the literature and thus reflect environmental conditions of the last decades.

BLUE is spatially explicit (unlike the country-level model by Houghton and Nassikas, 2017). It further tracks individual histories of successive land use change events in each grid cell, including their interactions.

A full model description including parameter choices has been published by Hansis et al. (2015).

1.2. Purpose of BLUE in VERIFY and planned adjustments of BLUE

BLUE provides a data-driven estimate of the net land use change flux that the dynamic global vegetation models (DGVMs) delivering priors to the inversions can use as independent validation. It will also be used to split the net land use change flux into different contributions (cropland expansion, pasture expansion, wood harvesting, abandonment). The model’s traceability allows uncertainties related to the input data and the influence of past land use change on net land use change flux to be tested. Fusion with data from DGVMs can be used to identify key differences between bottom-up estimates from process-based and bookkeeping methods.

In VERIFY, the standard setup of BLUE will be heavily adjusted to make use of the data richness in Europe. All datasets are provided from project partners. In particular, the land use transitions will be taken from the HILDA reconstruction and vegetation and soil carbon densities will be derived from forest inventories and the LUCAS soil database. In the present fast track analysis, however, we present, as baseline for the VERIFY improvements, the standard version of BLUE net land use change estimates.

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2. Latest published version of BLUE net land use change estimates

Starting with the Global Carbon Project (GCP) budget for 2017 (LeQuéré et al., 2018a), BLUE has been used as one of the two bookkeeping models providing the net land use change flux for the annual global carbon budget. The most recent version has been published as part of the global annual carbon budget 2018 (LeQuéré et al., 2018b). This most recent version is used in this deliverable.

2.1. Model internal structure

The model structure and parameterization of BLUE as published in Hansis et al. (2015) has not been modified. It will be modified for the final deliverable, see 1.2.

2.2. Input data on land use change

Major changes of the GCP budget 2018 version compared to the original BLUE publication (Hansis et al., 2015) stem from a change in input dataset for the land use transitions. While the Land Use Harmonization LUH1 (Hurtt et al., 2011) with updates for the recent years has been used in the original publication, LUH2 has been applied for the global annual budget publications. LUH2 is based on HYDE3.2 (History of the Global Environment; Klein Goldewijk et al., 2017). For HYDE, areas of cropland and pasture over time are obtained from the Food and Agriculture Organization of the United Nations (FAO) FAOSTAT Database. The areas are then made spatially explicit and hindcasted for the period before FAO data is available. Wood harvesting rates and gross transitions are added in LUH2 (Hurtt et al. in prep.).

Changes in input data from the GCP budget 2017 to 2018 were, apart from the usual extrapolation of HYDE/LUH2, the treatment of rangelands. A split into rangelands and pasture was requested by modelers to know if the natural vegetation type is grazed on, but remains, or if a land cover change occurs towards grasslands. In the HYDE version underlying LUH2, this split was done based on an aridity index, which does not fulfill the intended purpose. The BLUE curve published in the budget 2017 is the result of two BLUE simulations, which either treat rangelands as changing natural vegetation cover or not. Since then, an ancillary data layer was provided by LUH2: a “forest/non-forest map”, though disputable in its actual extent of forest, indicates whether natural vegetation should be cleared for rangeland expansion (if forest) or not (if non-forest). Consequently, the budget 2018 BLUE estimate is based on just one

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simulation.

3. Fast Track Analysis of BLUE for European countries

Figure 2 aggregates the spatially explicit BLUE results for the European countries. Results are shown for the last decades, the most relevant period for VERIFY.

BLUE results are compared against the bookkeeping estimate by Houghton and Nassikas (2017), who provide generally the same definition of the net land use change flux. Large differences exist, however, in two respects: (1) Assumed carbon densities: These are biome-specific from literature values in BLUE, but taken from FAO for Houghton and Nassikas (2017). (2) Underlying land use change data: This is LUH2 at 0.25 degree resolution for BLUE, but based directly on FAO country level data in Houghton and Nassikas (2017). A factor separation by exchanging just land use or just carbon densities between BLUE and the Houghton and Nassikas model is beyond the scope of this fast track analysis, but on its way.

BLUE results are also compared to the TRENDYv7 data. TRENDYv7 comprises 16 DGVMs that contributed to the 2018 annual carbon budget (LeQuéré et al., 2018b). DGVMs are fundamentally different from bookkeeping models in that they resolve explicitly the biophysical processes underlying carbon fluxes such as photosynthesis and respiration. The DGVM spread is large (globally 1.9 PgC/year on average for the 2008-2017 period with a standard deviation of 0.6 PgC). But differences to the bookkeeping approaches can be even larger. An important point here is that DGVMs respond to environmental changes, both concerning interannual timescales (which creates the larger interannual variability discernible in Fig. 2) and concerning long-term trends. Long-term trends occur because the models are driven by historical changes in climate, CO_2 and nitrogen deposition. These changes in environmental conditions are on average beneficial for vegetation growth, leading to additional carbon sequestration in particular in forests. This sink gets lost when forests are replaced by agriculture. Since the net land use change flux in DGVMs is calculated from the difference of a simulation with land use change and one with land use kept fixed at the 1750 distribution, DGVMs include the loss of additional sink capacity (Gitz & Ciais, 2003; Pongratz et al., 2014; Stocker and Joos, 2016). This creates generally higher emissions for deforestation, but also larger uptake over time for forest regrowth, compared to bookkeeping approaches.

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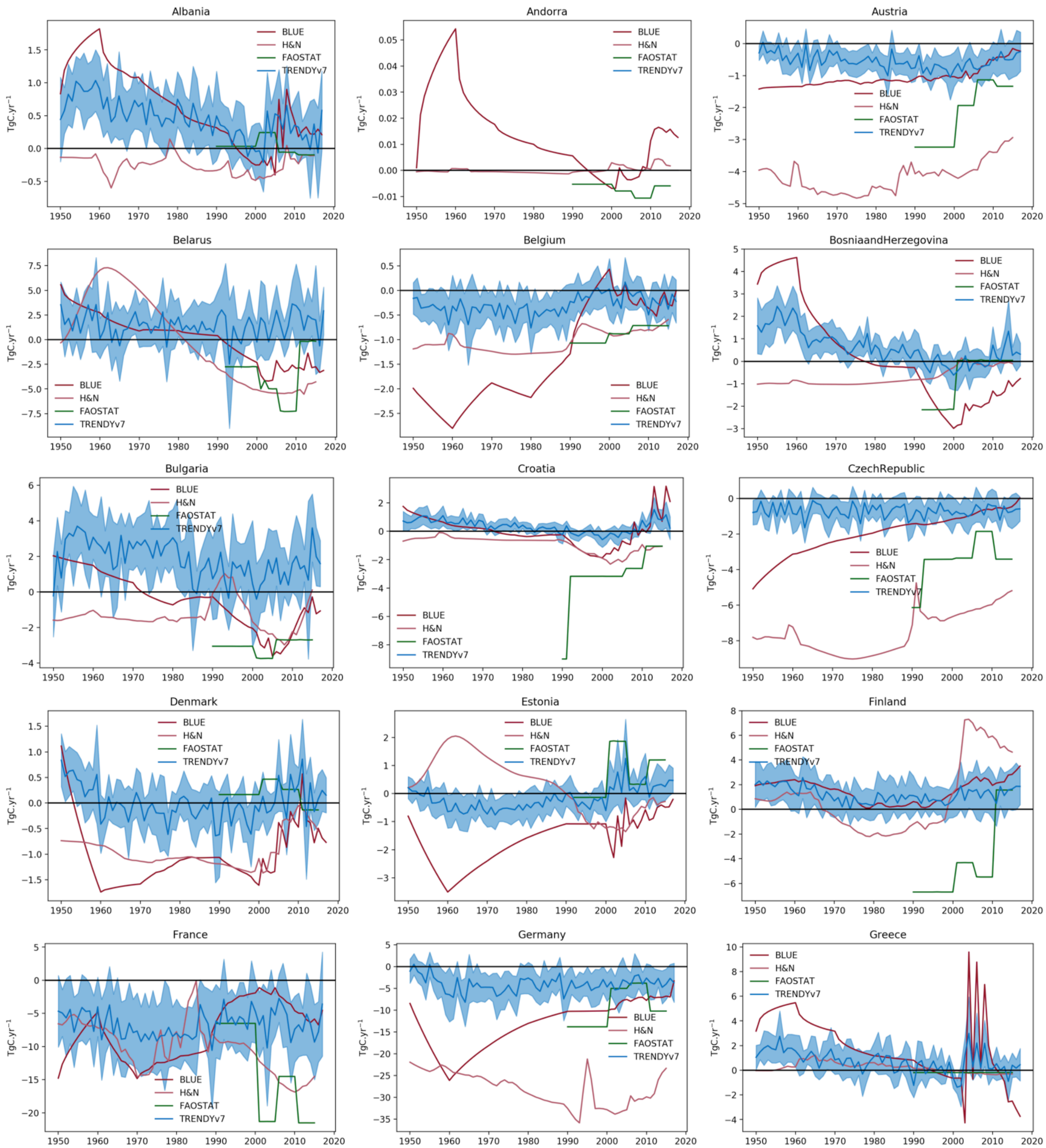

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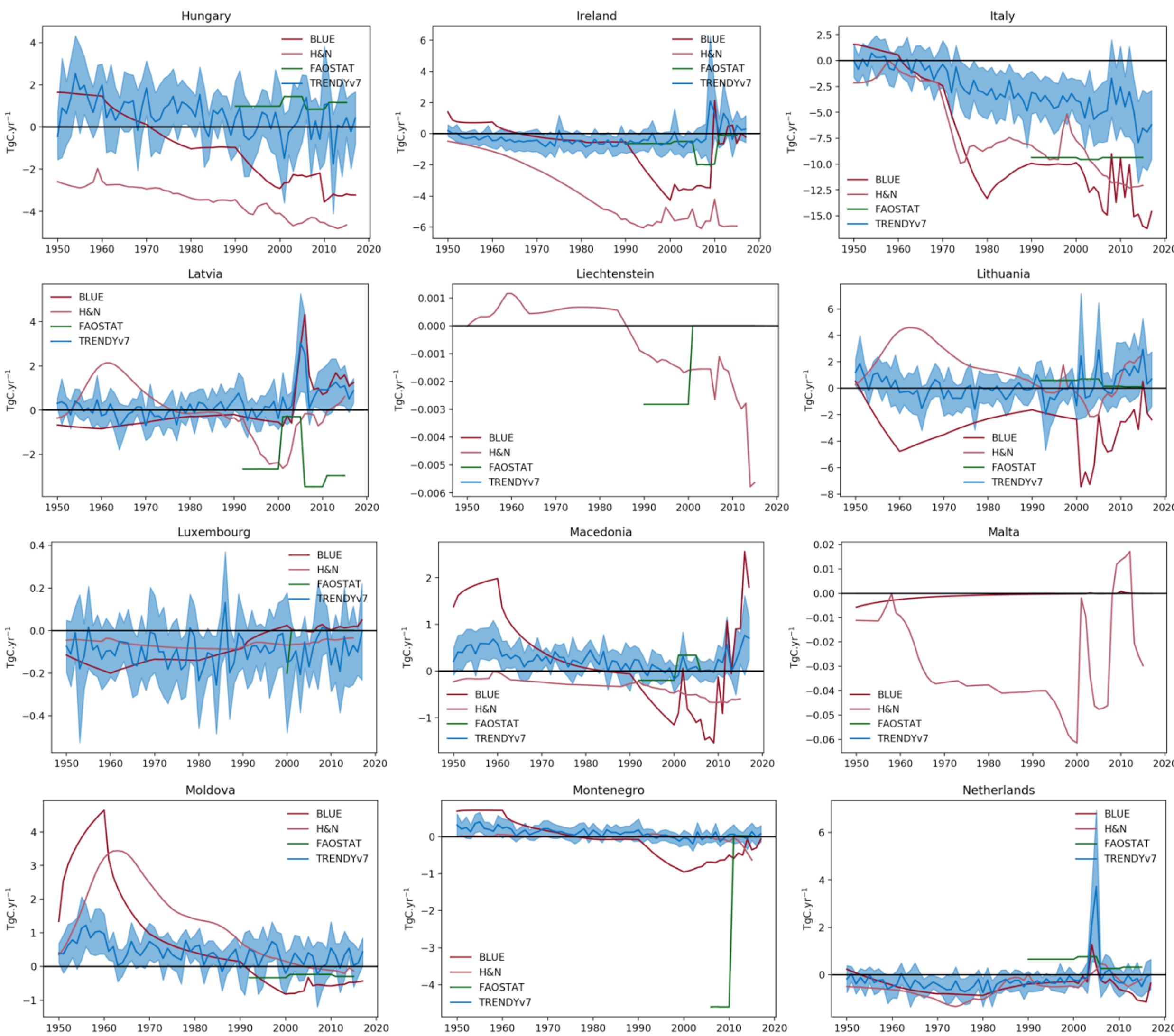

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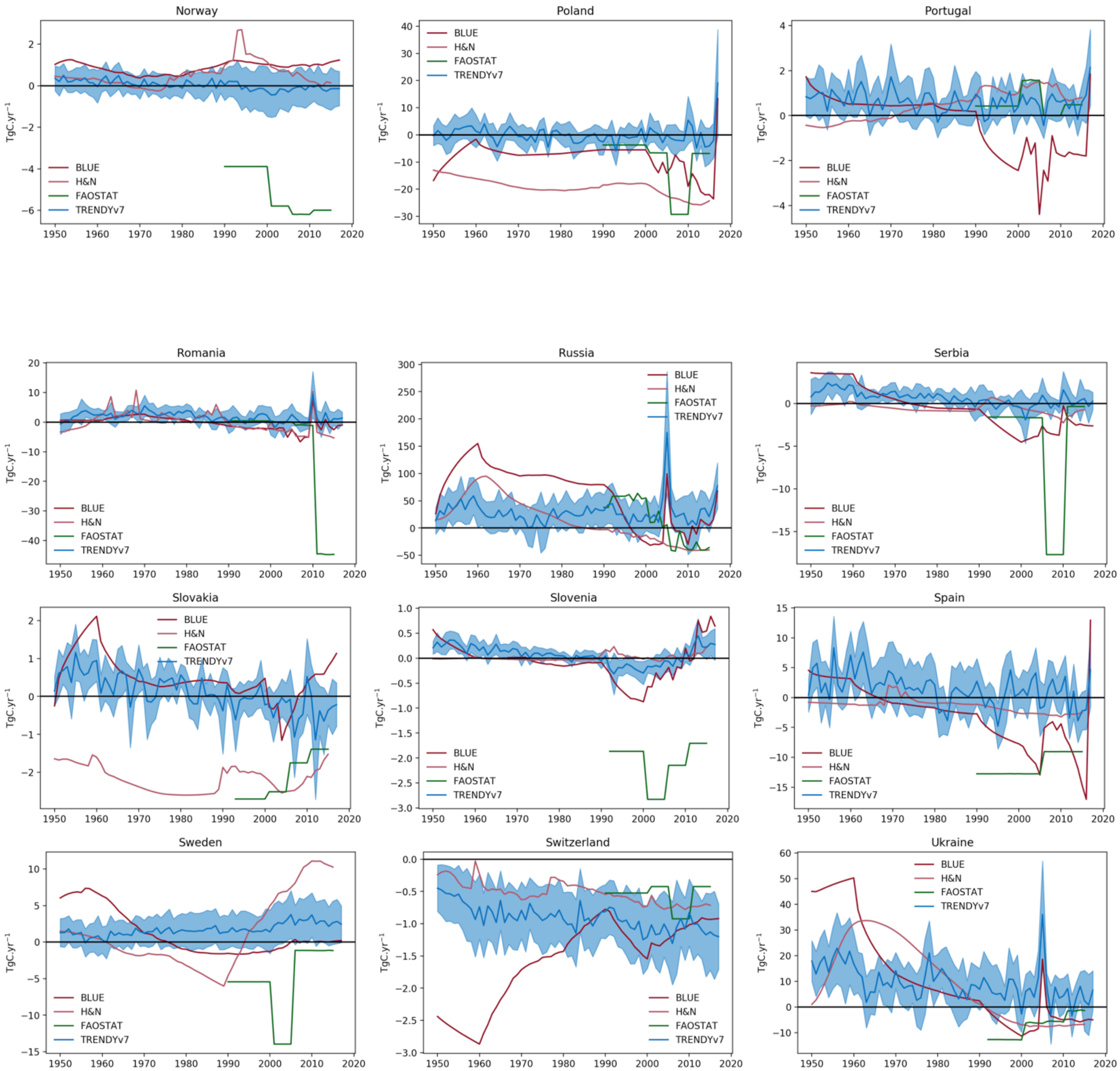

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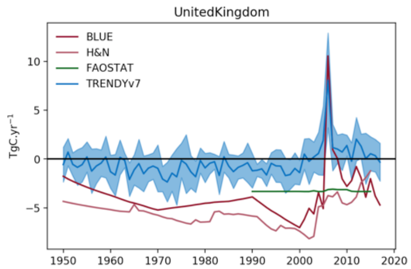

Fig. 2 Estimates of the net land use change flux for all European countries. Datasets are taken from three modeling approaches as published in the annual global carbon budget 2018 (LeQuéré et al., 2018b): the Bookkeeping of Land Use Emissions model (BLUE), which will also be used in VERIFY; an alternative bookkeeping model (Houghton and Nassikas, H&N); 16 dynamic global vegetation models (TRENDYv7). For comparison, FAOSTAT Land Use Total Emissions are also shown. BLUE and the TRENDYv7 models are spatially explicit and have been aggregated to the country-level for the purpose of this analysis.

BLUE results are also compared to the net land use change flux from FAOSTAT (http://www.fao.org/faostat/en/#data; "Emissions" > "Land Use Total"). FAOSTAT numbers are based on inventories and other direct observations of carbon stock changes and therefore include natural sink terms in their estimate as well, which are excluded in both bookkeeping and DGVM definitions of the net land use change flux (Pongratz et al., 2014). FAOSTAT values must therefore be expected to generally produce smaller emissions into the atmosphere/larger sinks on land than DGVMs and bookkeeping models.

Large differences between BLUE and Houghton and Nassikas (2017) occur in the early part of the 20th century with BLUE exhibiting a spike in emissions in Albania, Andorra, Bosnia and Herzegovina, Macedonia, Moldova, Russia, Slovakia, Ukraine. The reason for this lies in the way land use is hindcasted in HYDE: Since FAO land use data starts in 1960 only, HYDE hindcasts land use prior to this. For the hindcast it uses population data and the per-capita land use values of 1960, often with slight modifications of the per-capita value taken from nearby countries if land use estimates happened to have been available there for earlier time periods. Overall, however, the dependence on population of the resulting hindcasted agricultural areas is strong. This process often leads to a break in the land use area trends, which generally do not depend strongly on population in the post-1960 period and show only small trends compared to population. Consequently, in countries that have an increase in population in the time period up to 1960 large increases in agricultural land are calculated by HYDE, which lead to large emissions. These emissions then cease when the land use area information switches to areas directly reported by FAO. The problematic nature of population-based hindcasting is exemplarily shown in Fig. 3.

Unlike Houghton and Nassikas (2017), BLUE features spikes in emissions (sudden large emissions in a single year) in Latvia, the Netherlands, Romania, Russia, Ukraine and the U.K. These spikes are also seen in the TRENDY models. Since both BLUE and TRENDY are run with the same land use forcing (LUH2), while Houghton and Nassikas (2017) uses FAO, these spikes can be attributed to LUH2 and are likely artifacts. These are expected to be eliminated when the HILDA forcing is used in VERIFY.

Another artifact from the land use forcing is the sudden increase in variability discernible in most countries after 2000. The reason is that HYDE put out annual values only starting 2000; before 2000 only decadal values were provided to LUH2. Houghton and Nassikas (2017) by contrast provide 5-year averages, but consistently throughout their time series.

Other country-specific differences can be observed, but they will be analyzed if they still occur in the BLUE runs using HILDA.

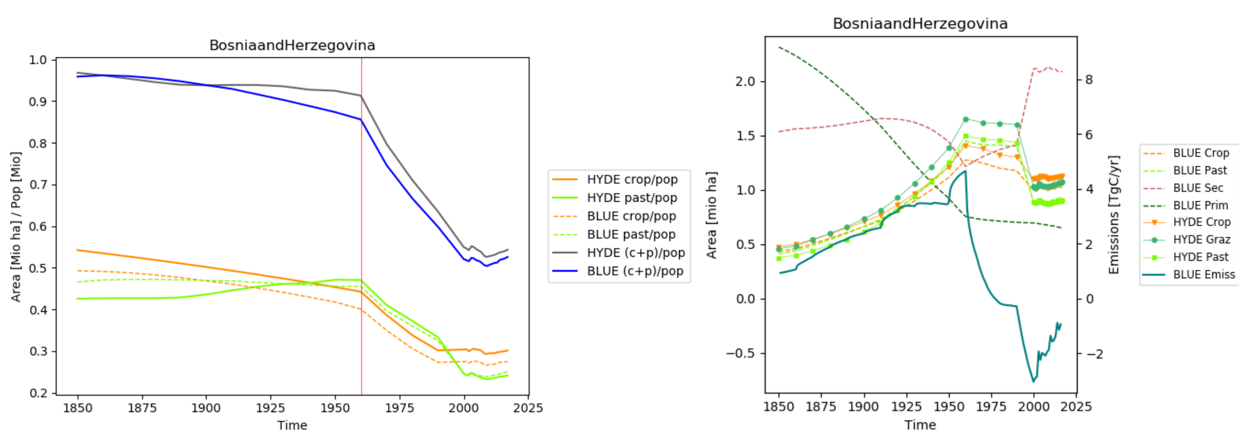

Fig. 3 A country example for the discontinuities arising from hindcasting land use area with near-constant

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per-capita values prior to the FAO era, which starts 1960. Left panel shows per-capita land use area for BLUE and the current HYDE version, right panel shows the evolution of land use areas (crop, pasture, grazing) and the net land use change flux, with its typical peak in the 1950s.

4. Summary

The fast track analysis compares BLUE to another bookkeeping approach (Houghton and Nassikas), to dynamic global vegetation models (DGVMs), and the land use total emissions reported by FAO. Generally higher emission estimates than FAO can be attributed to different ways of reporting/accounting. Likely artifacts of LUH2 are revealed by BLUE and the DGVMs: these include an emission peak due to change in data source in 1950s, sudden increase in variability in 2000 and emissions peaks in individual years and countries. Other differences between BLUE and Houghton and Nassikas stem from differences in assumed carbon densities. Since land use forcing and carbon densities will be updated in VERIFY, we foresee an improvement in BLUE estimates within the next two years.

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