Global Climate Regulation Services

Deliverable 3: Global Results

under the KM-GBF Project between UN-DESA and BC3

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Index

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Overview of Global Climate Regulation Services

Global climate regulation services are ecosystem contributions to reducing concentrations of GHGs in the atmosphere through the removal (sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems (SEEA-EA Table 6.3). Terrestrial ecosystems absorb about one third of the emissions caused by human activities (Canadell 2025). The loss and degradation of terrestrial, coastal and marine ecosystems worldwide threatens the ability of these ecosystems to act as carbon sinks.

This module aims to begin addressing a critical global data gap by developing annual layers based on the IPCC Tier 1 'stock-difference' methodology. This approach covers all terrestrial ecosystems, as well as mangroves, which are transitional marine-freshwater-terrestrial ecosystems. The module does not address carbon sequestered and stored in marine ecosystems. The 'stock-difference' approach uses repeated inventories of carbon stocks, and the loss or gain of carbon is derived as the difference between two time steps. As well as demonstrating areas important for carbon storage globally, this model can be applied to time-series data to identify where substantial changes are taking place over time. Specifically, where substantial accumulation (sequestration) or losses (emissions) of carbon are occurring. This method is the most commonly used approach to model carbon storage distribution and change. Following the 'Tiers' outlined in UN (2022), this model represents a Tier 1 approach of the 'stock-difference' method using IPCC default emissions factors, with some Tier 3 components including ancillary data used to establish forest ages and class. Adjustment of the input emission factors/carbon stock table to include national-level data would represent a Tier 2 model.

A global carbon storage model is currently available in ARIES for SEEA. However, this model is based solely on the 2006 IPCC guidelines and out-of-date input data. This update to the ARIES global climate regulation model aims to synthesise updated IPCC carbon stock and sequestration data (IPCC 2013; 2019), and integrate state-of-art remote-sensed ancillary data products to map carbon distribution and change over time globally. Furthermore, the method is developed to provide flexibility in input datasets through the ARIES system should users wish to use alternative data inputs and spatial and/or temporal scales (where capacity and resources are available).

Methodological documentation of the global climate regulation module

We have compiled a database of carbon stock and sequestration factors for each natural/semi-natural land cover type (as defined by the IPCC), stratified by climate, continent and ecological zone. These values reflect the latest updates to IPCC data and methodological guidelines. As explained above, all terrestrial ecosystems (and mangroves) are considered in this approach.

Forest (and some shrub) land cover classes are defined by continent, Global Ecological Zone (GEZ), management practices and age. Forest classes are stratified into Primary Forest, Secondary Old, Secondary Young, Plantation Old and Plantation Young, as per IPCC (2019) tables. The stratification methodology (Figure 1) utilises global and regional datasets to identify each forest type, aligned with methodologies employed by Bourgoin *et al*. (2025) and Hunka *et al*. (2024). Datasets were selected based on geographic coverage, spatial and temporal resolution. The baseline year for the analysis will be 2020. Therefore, all 'young' forest cells in 2020 are assigned an approximate age, which will be updated for further analysis years to ensure additional carbon sequestered through growth is applied (Figure 2). Any new forest cells appearing in subsequent years will be assigned an age of 3 years (assuming some years of growth have occurred before satellite-based algorithms flagged them as forest pixels).

The final intermediate input of forest type globally was then compared to both Bourgoin *et al*. (2025) and Hunka *et al*. (2024) for validation purposes. It should be noted that they have slightly different classes, Bourgoin *et al*. (2025) do not split secondary forest into young (<20 years age) and old (>20 years age), and Hunka *et al*. (2024) do not include plantation forest classes.

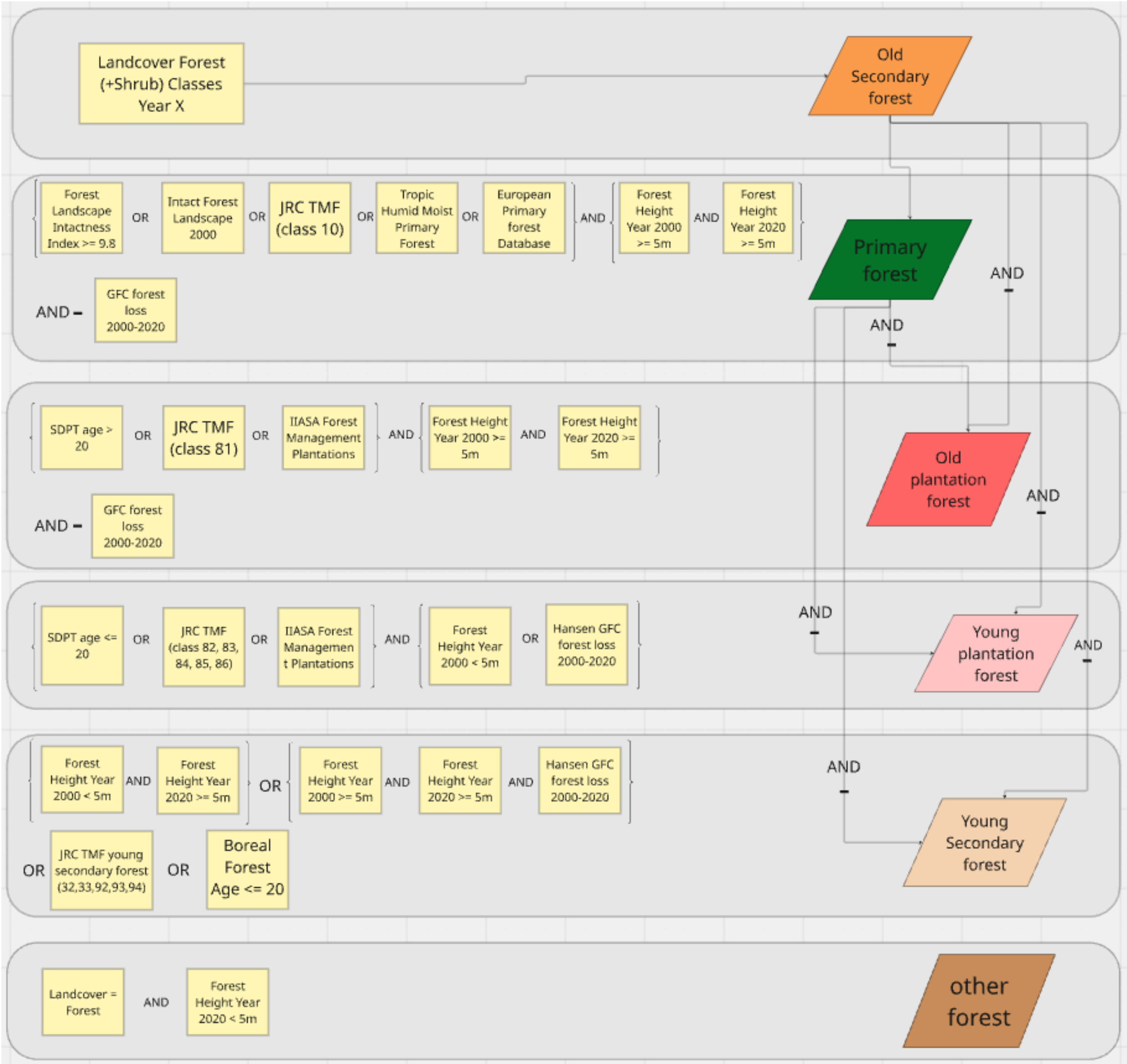

Figure 1. The workflow for assigning forest types to forested land covers. Ancillary datasets (yellow) are used to distribute forests into forest types aligned with the definitions and methodologies of IPCC (2019). The methodology is based on Bourgoin et al. (2025) and Hunka et al. (2024). Pixels assigned as forest by the land cover product, but with a forest height of below 5m were categorised as 'other forest' and assigned a lower carbon stock value. Pixels classed as forests and overlapping with agroforest in the IIASA forest management dataset were classed as agroforests and treated as non-forests (perennial cropland).

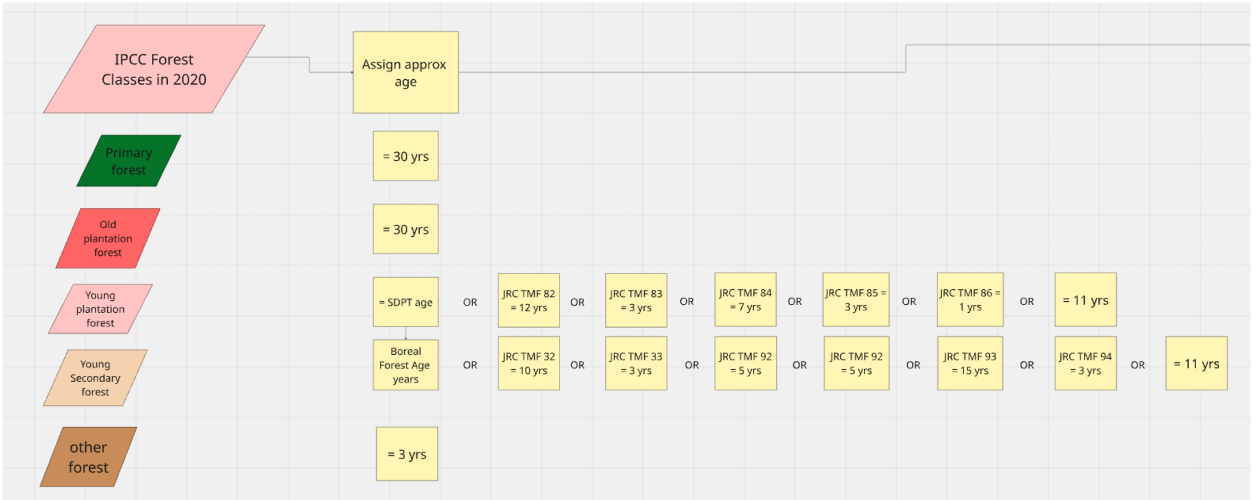

Figure 2. The logic used to assign approximate ages to different forest types. For Primary and 'Old' forest types, the age is not used to assign an approximate carbon value, only for those forests classed as young. Where datasets of tree age or planting year exist, they are used to assign approximate ages, otherwise, default ages are used.

Non-forest classes (including mangroves) are defined by continent and IPCC climatic zone to identify vegetation types as defined by the IPCC guidelines (IPCC 2006, 2013 and 2019). These classes are used to select and record appropriate aboveground biomass stock and sequestration values from the latest IPCC guidelines. Belowground biomass is estimated from IPCC default values for the different land use types (IPCC 2006; 2019). Finally, carbon fractions are applied to convert biomass values to estimate biomass carbon stock and sequestration values (IPCC 2006; 2019). Cropland values are supplied in terms of tonnes C per hectare, and therefore do not require conversion.

The combination of forest and non-forest values is outlined in Figure 3.

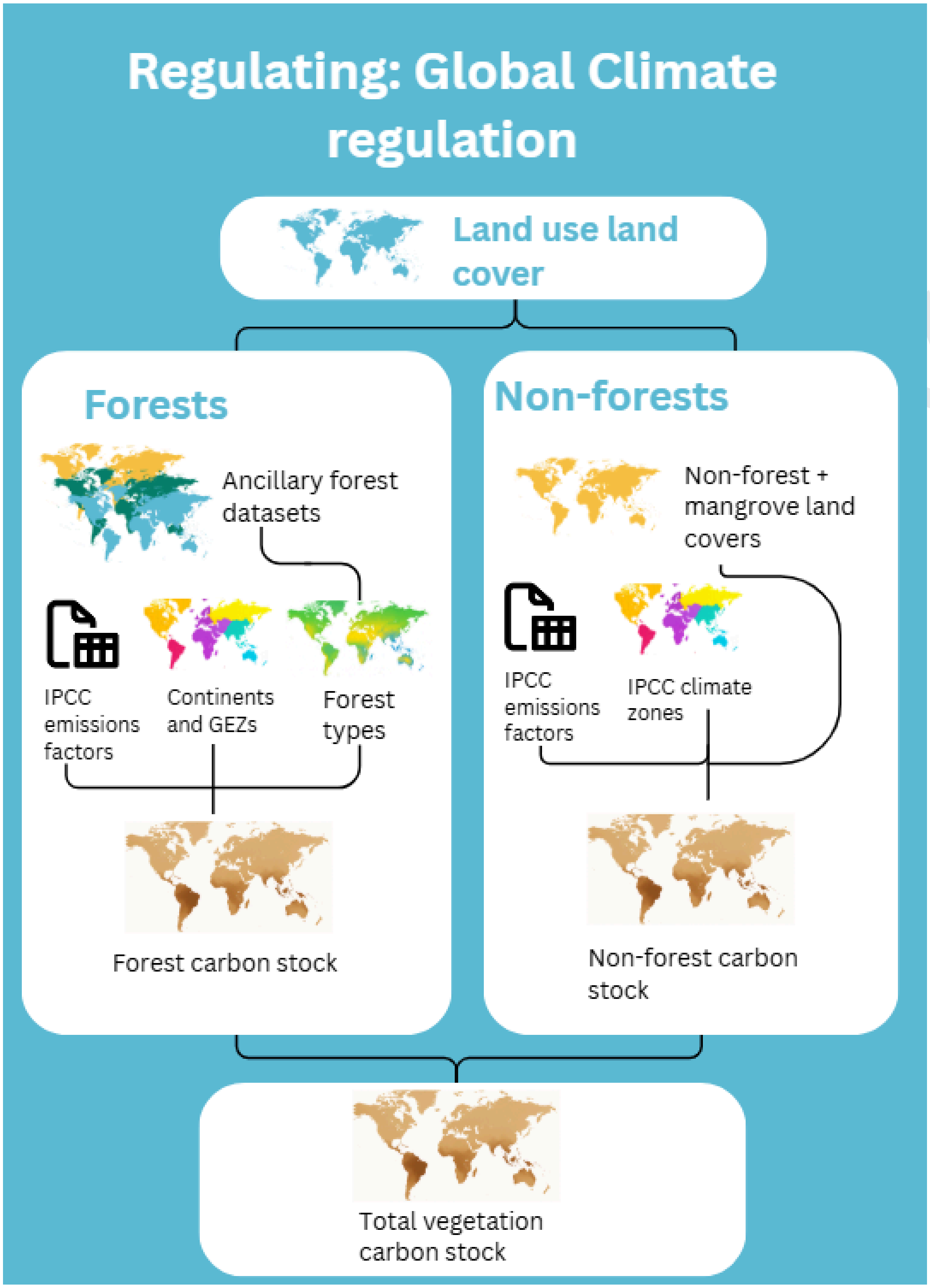

Figure 3. Broad workflow for assigning appropriate carbon stock values depending on ecosystem and geographic location to generate a global map of biomass carbon stocks in the year X. IPCC forest types are derived from the workflow presented in Figure 1. GEZ = Global Ecological Zones.

When estimating change over time, IPCC guidelines are followed to estimate annual increases in carbon stocks. It is therefore assumed that grassland and cropland steady-state vegetation biomass carbon stocks are achieved during the first year following conversion of land to these land cover classes. In forests, the IPCC default assumption of reaching age 20 years to achieve steady state carbon stocks is applied. Annual carbon stock maps are compared to produce an annual proportional change layer. To incorporate natural variation within land cover class, the proportional change layers are applied to a global, remote-sensing derived vegetation carbon layer (e.g., Spawn *et al.* 2020).

The distribution of soil organic carbon (SOC) will be mapped using newly available global spatial datasets (likely Creze *et al.* In prep).

The approach is developed using a flexible, transparent modelling approach which can be adjusted to include different landcover inputs or carbon stock factors (based on capacity and resource availability). Additionally, it can be adapted as improved datasets become available.

Data Inputs

The global annual landcover dataset GLC_FCS30D (Zhang *et al.* 2024) was selected due to its high temporal and spatial resolution (1985-2022, 30m), as well as breadth of landcover classes. The land cover classes are mapped to IPCC land cover classes to apply appropriate carbon stock values.

Ancillary spatial datasets are used to add further data to the land cover classes to enable the application of the correct carbon stock and/or sequestration value. This included forest status (primary forest, secondary forest and plantation forest, see figure 1 above), as well as age of forest in the case of secondary and plantation forests (see figure 2). Where possible, we have tried to select datasets with high spatial and temporal resolution. In some cases, there may not be data available which is temporally aligned with the reporting year. Where this happens, the limitation is noted and the next best source of available data will be used. Over the course of the reporting periods, new data may become available. Therefore, the input datasets and sources may change over time.

Classes relating to water, snow/ice and no data will be treated as no data and excluded from the analysis. Landcover classes including urban, bare rock and sand are assumed to have zero biomass carbon (IPCC 2006; IPCC 2019). Furthermore, coastal and marine ecosystems (excluding mangroves) are not included in this module to limitations both in the spatial mapping of them, and in the availability of carbon stock factors and methodologies from the IPCC guidelines.

Landcover classes are further combined with a GEZ dataset (FAO 2012), IPCC climate zones (JRC 2010) and continents to apply appropriate biomass values, carbon fractions and root:shoot ratios. These inputs are combined to estimate the total biomass carbon stock per cell.

Finally, the vegetation carbon stock layer is combined with a global soil organic carbon (SOC) stock layer. The final resulting layer demonstrates the distribution of both vegetation and soil organic carbon globally.

Table 1. Input layers, their source and purpose in the proposed global climate regulation module.

Layer	Producer	Purpose	Spatial and Temporal coverage
GLC_FCS30 land cover layer	Zhang *et al.* 2023	Identify spatial coverage of IPCC landcover classes	30m, Annual (1985-2022). Further updates TBC
Global Ecological Zones	FAO (2012)	Delineate forest ecological zones for assigning carbon stock values	Polygon, 2010 no updates expected
IPCC Climate Zones	JRC (2010)	Delineate non-forest climatic zones for assigning carbon stock values	10km, 2000. No updates expected, but it can be downscaled for future iterations
Intact forest landscapes	Potapov *et al.* 2017	Delineation of primary forests	Polygon, 2000, 2013, 2016, 2020, 2025. Potential updates
Primary Humid Tropical Forests	Turubanova *et al.* 2018	Delineation of primary forests	30m, 2001. Updates TBC
Tropical Moist Forests transitions (1990-2024)	Vancutsem *et al.* 2021	Delineation of tropical forest types	30m, 1990-2024. Updates expected
Global forest landscape integrity index	Grantham *et al.* 2020	Identification of primary forests (score of >= 9.8)	300m
European Primary Forest Database 2.0	Sabatini *et al.* 2021	Identification of European primary forests (all polygons in database)	Polygon, rasterized to study resolution

GLAD Global Forest Canopy Height	Potapov *et al.* 2022	Distinguishing between young and old forests	30m, 2000 and 2020
Tree cover gain (2000-2020)	Potapov *et al.* 2022	Delineation of secondary young forest	30m, 2001-2020 (not annualised).
Forest management dataset	Lesiv *et al.* 2022 or Neumann *et al.* in review	Delineation of plantation forests	100m, 2015 (updates not expected), or 10m 2020
Planting years of plantations	De *et al.* 2022 (Based on Spatial Database of Planted Trees)	Estimating age of plantation forests and tree crops (e.g. oil palm)	30m, 1982-2020 (currently based on SDPT v1, now v2 released).
Boreal forest stand age	Feng *et al.* 2022	Estimating the age of boreal secondary and plantation forests	30m, 1984-2020
Global distribution of root mass fraction	Ma *et al.* 2021	Spatially distributed R factors (IPCC factors used as default where data gaps exist)	1km, static
Global distribution of Soil Organic Carbon (SOC) Stocks *	Hengl *et al.* 2025 or Creze *et al.* 2025	Spatial distribution of Soil Organic Carbon stocks	30m 2000-present annual

N.B. All input layers listed in Table 1 are subject to change should improved datasets be identified during the modelling and testing phases. All input datasets exist at different scales, and undergo preprocessing to be used at the target scale (100m). Input datasets are of varying temporal scales. Data representing the closest year to the target year will be used in the model.
** Not yet added to the model as data not yet published.*

Notes on the global runs

Due to the large number of independent datasets used to estimate vegetation carbon stock, there are varying degrees of certainty in the results globally. Additionally, the differences in spatial and temporal scales of the datasets can introduce some errors or limitations to the model. For example, the global climate zones (JRC 2010) dataset has some missing data in some coastal areas and small islands due to the spatial resolution of the dataset. An approach to increase the resolution and gap fill these areas is being investigated. For now, there are some gaps in the data because of this.

The model will be updated to incorporate new global datasets on ecosystem extent, replacing the use of land cover land use data in the model.

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