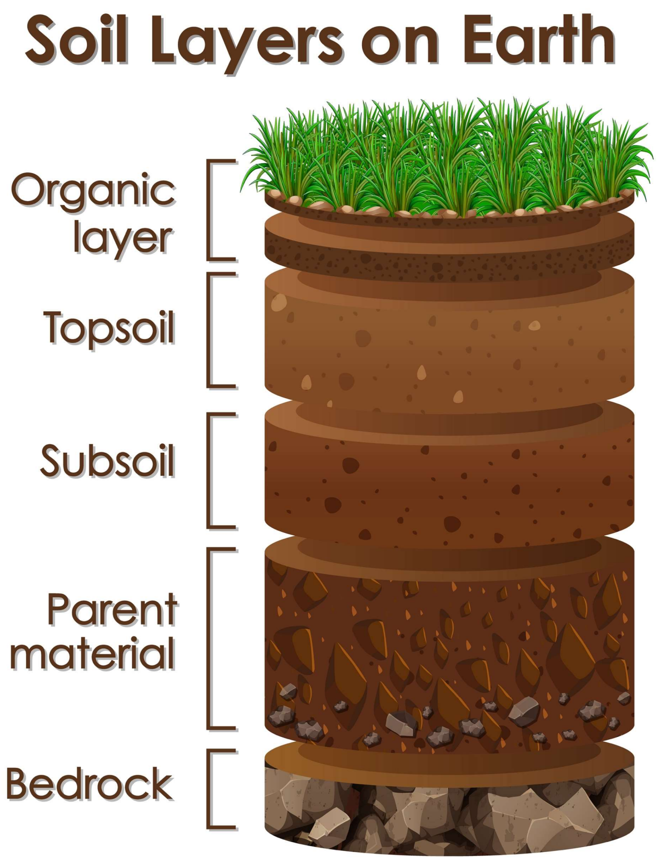
Département de GÉOSCIENCES

Webinar on Soil Organic Carbon to Support National Greenhouse Gas Inventories from Developing Countries under the Enhanced Transparency Framework of the Paris Agreement



Session 3

Approaches for estimating soil organic carbon

On the estimation of soil organic carbon dynamic

GUENET Bertrand
LG-ENS
guenet@geologie.ens.fr

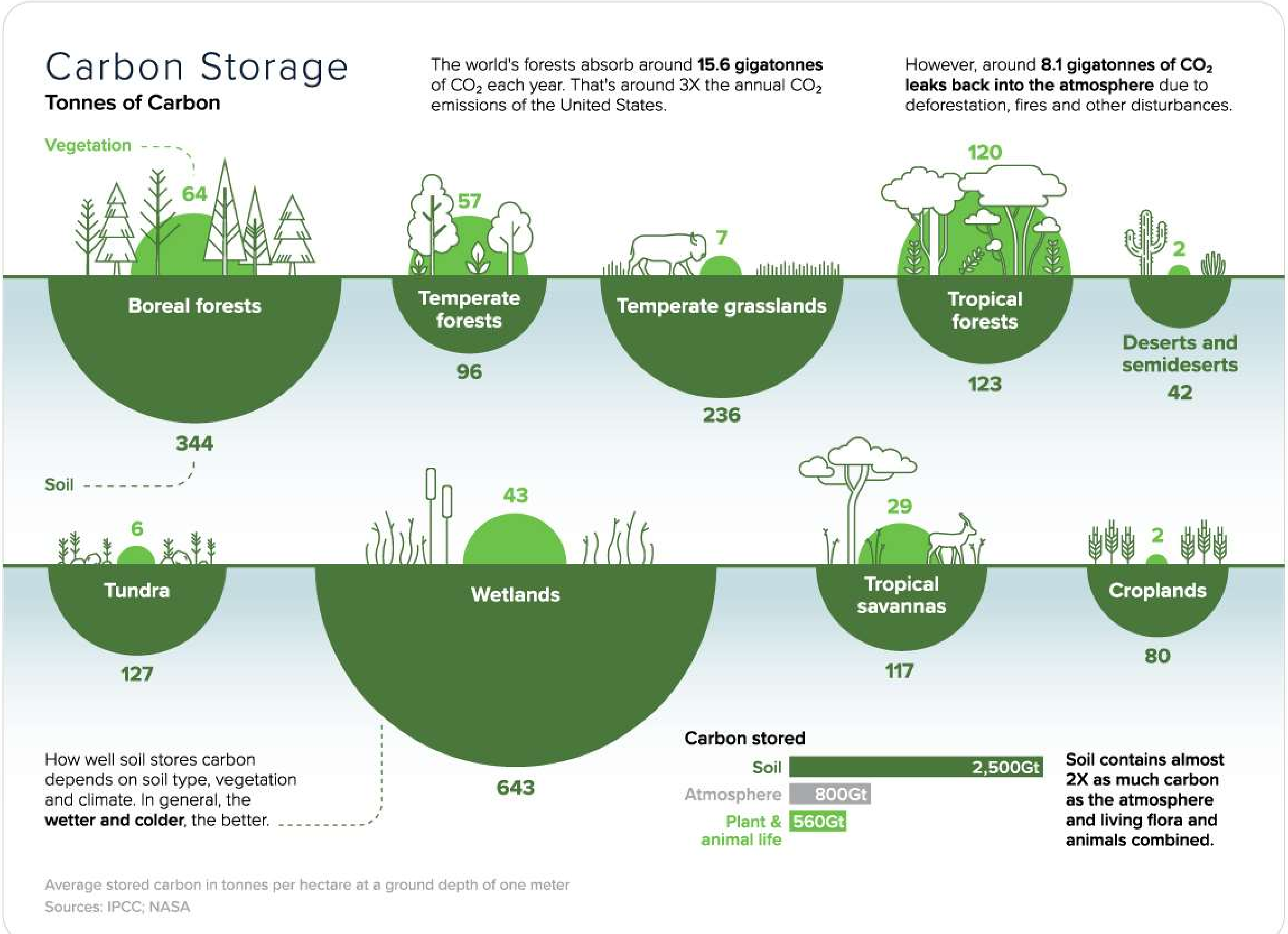
OBJECTIVES OF THE SESSION

- Better understand the tier 1, tier 2 and tier 3 methods from the 2006 IPCC Guidelines
- Learn the limitations of each tier method

CONTENT

- Introduction
- Description of the methods
- Some specificities link to soil carbon
- Examples of situations that may lead to a misuse of the Tiers methods.

WHY SOIL ARE IMPORTANT ?



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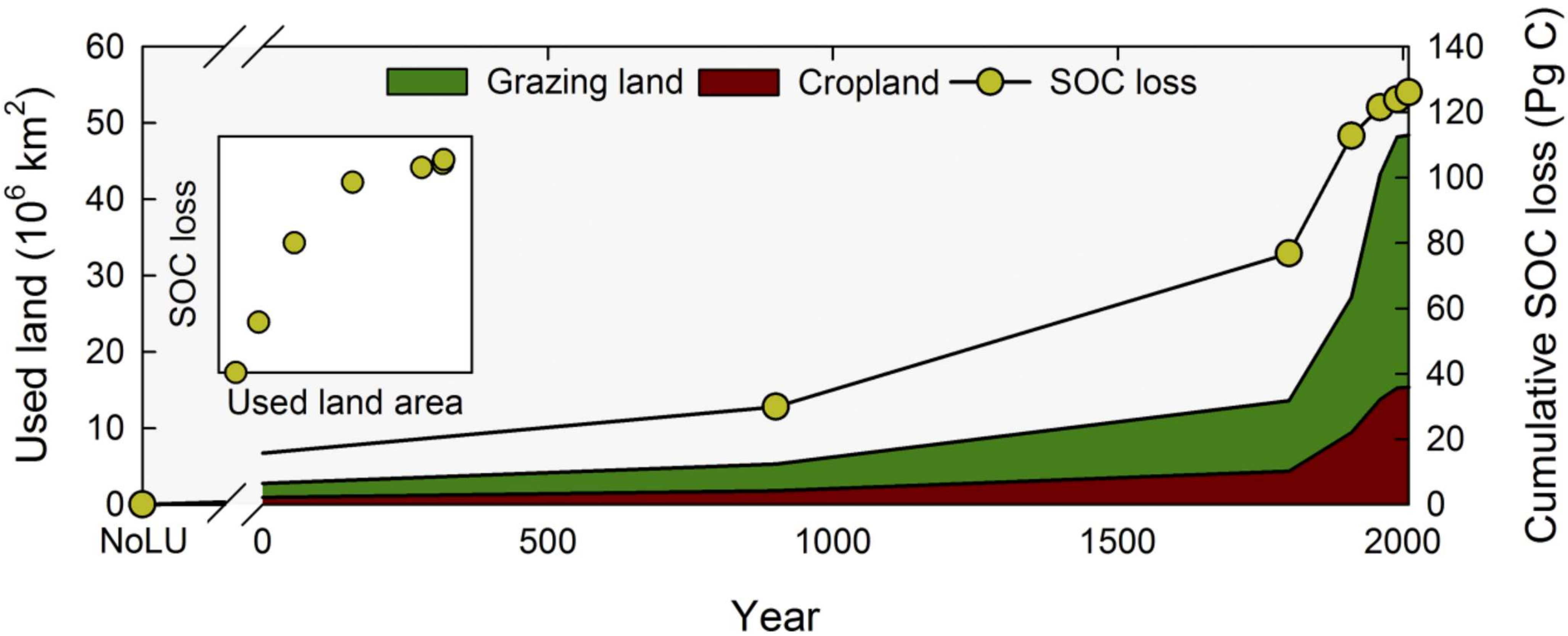
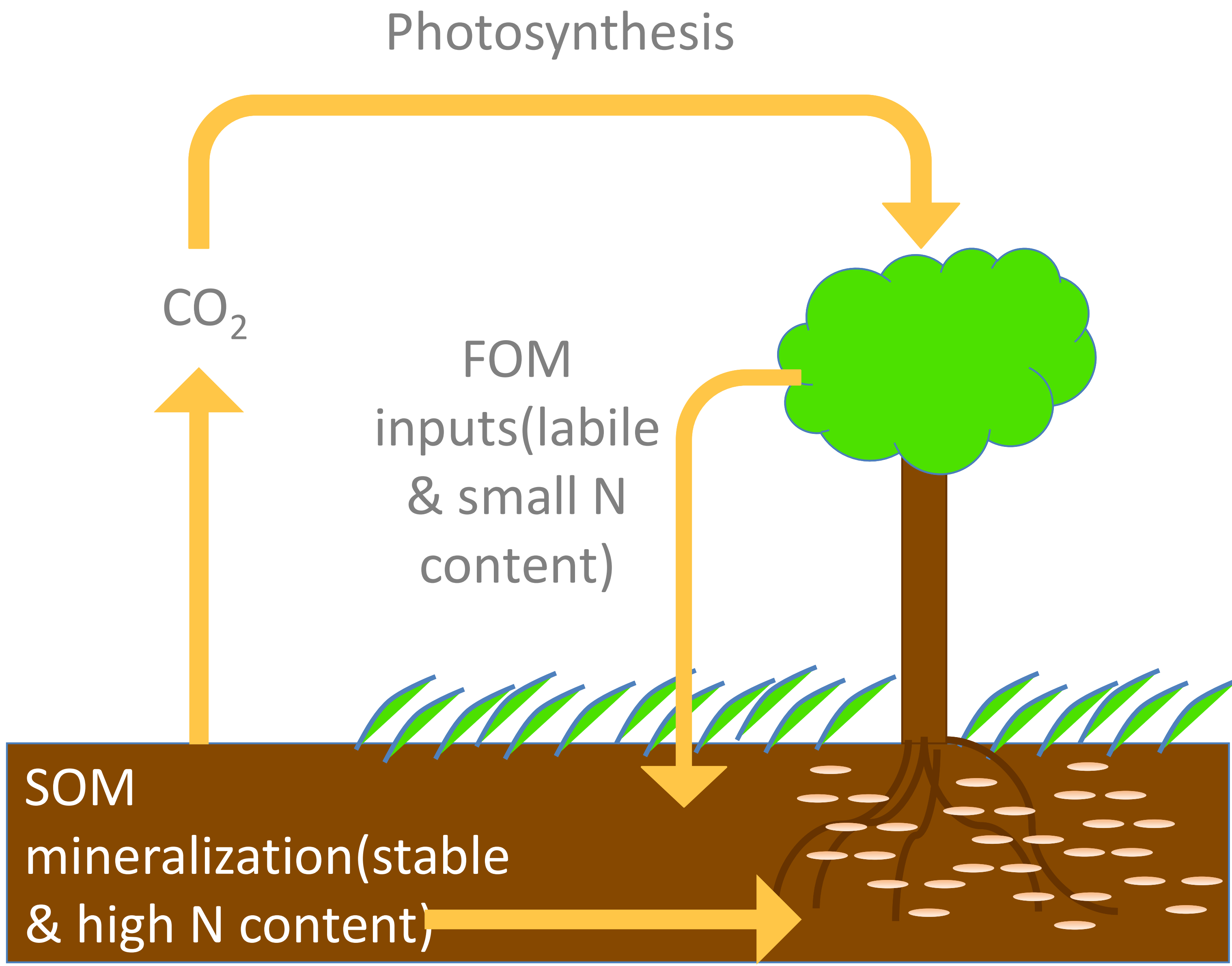


Sanderman et al., 2017

SOILS: MAJOR ACTORS OF THE C CYCLE



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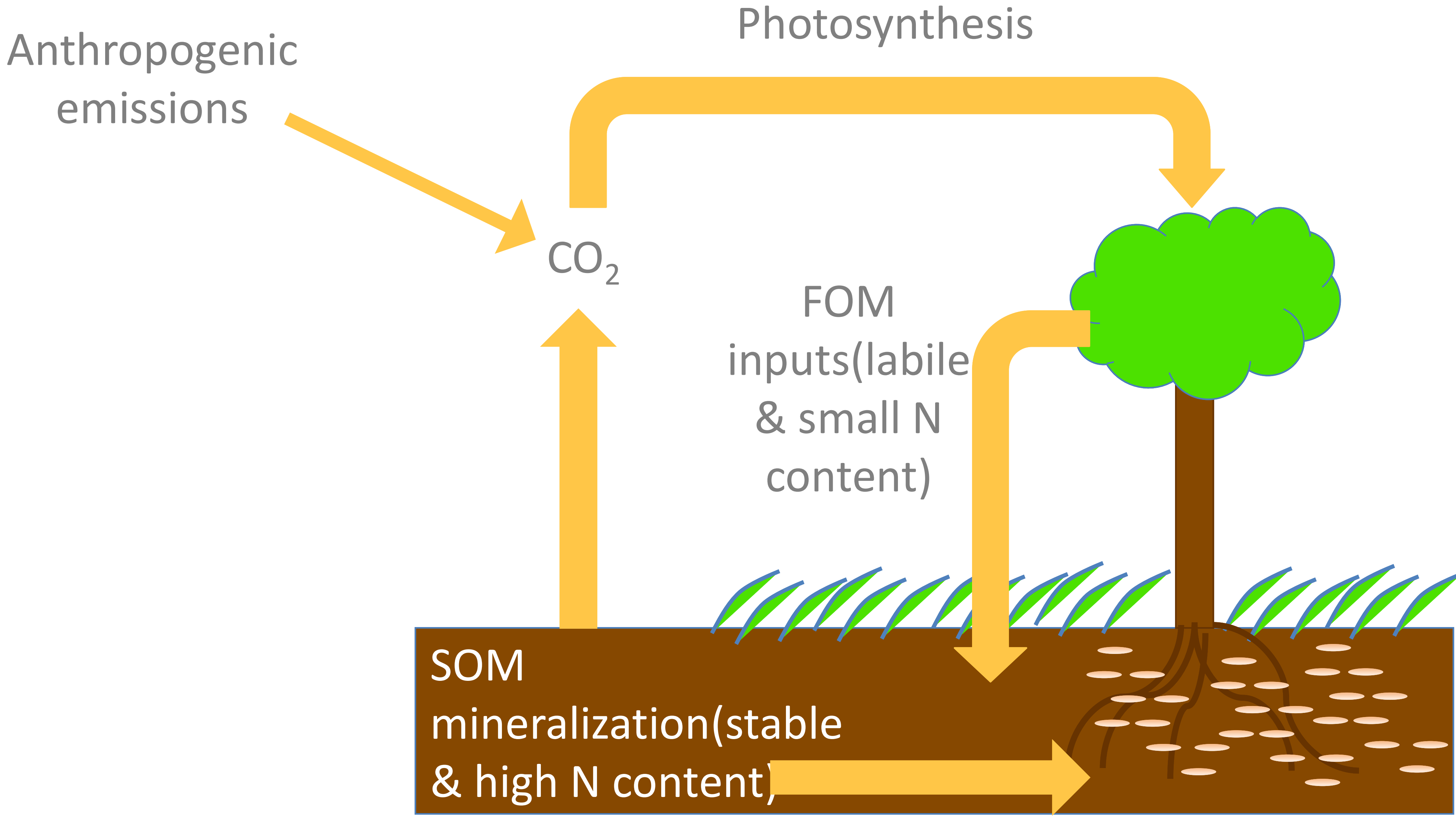
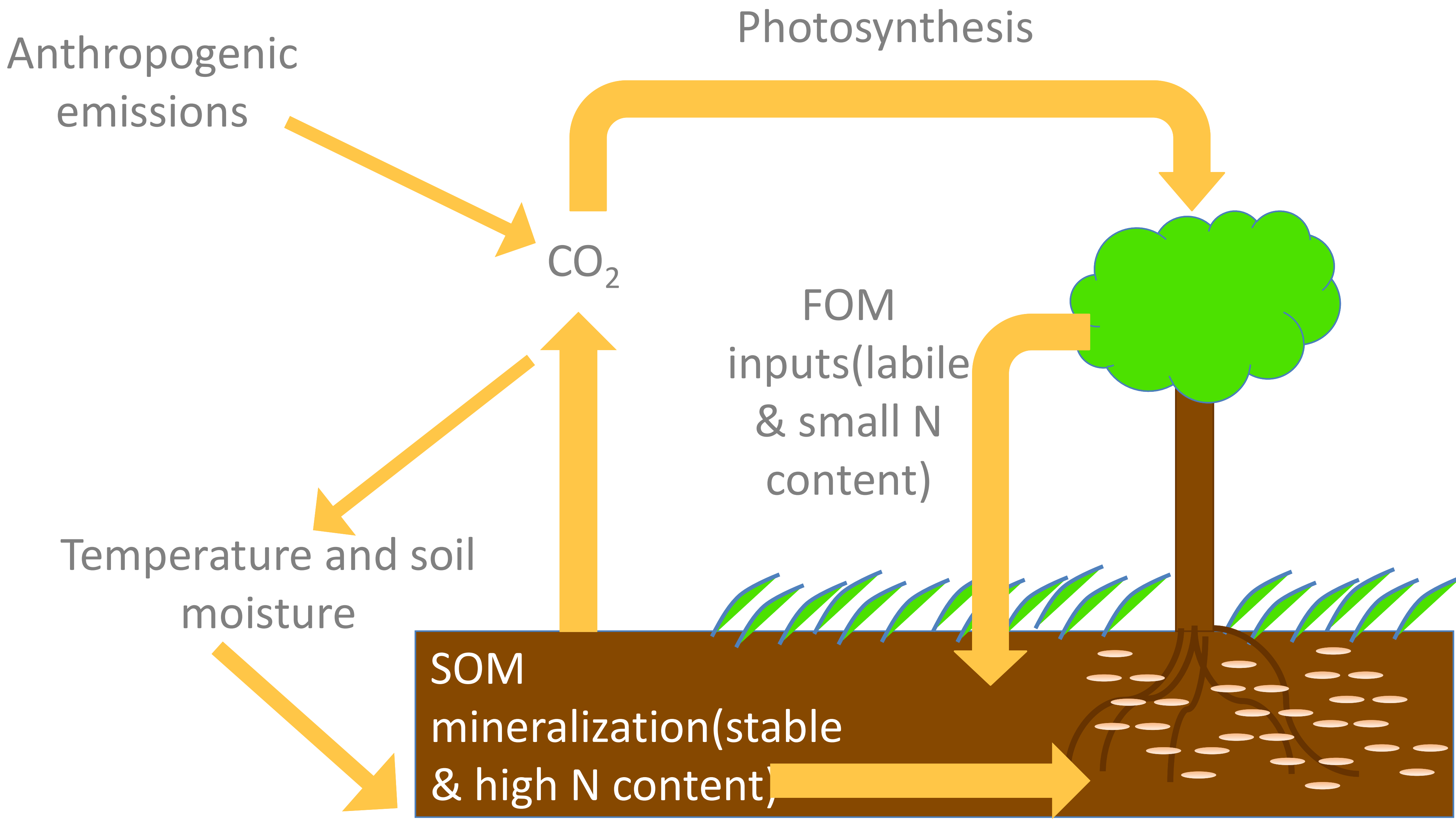
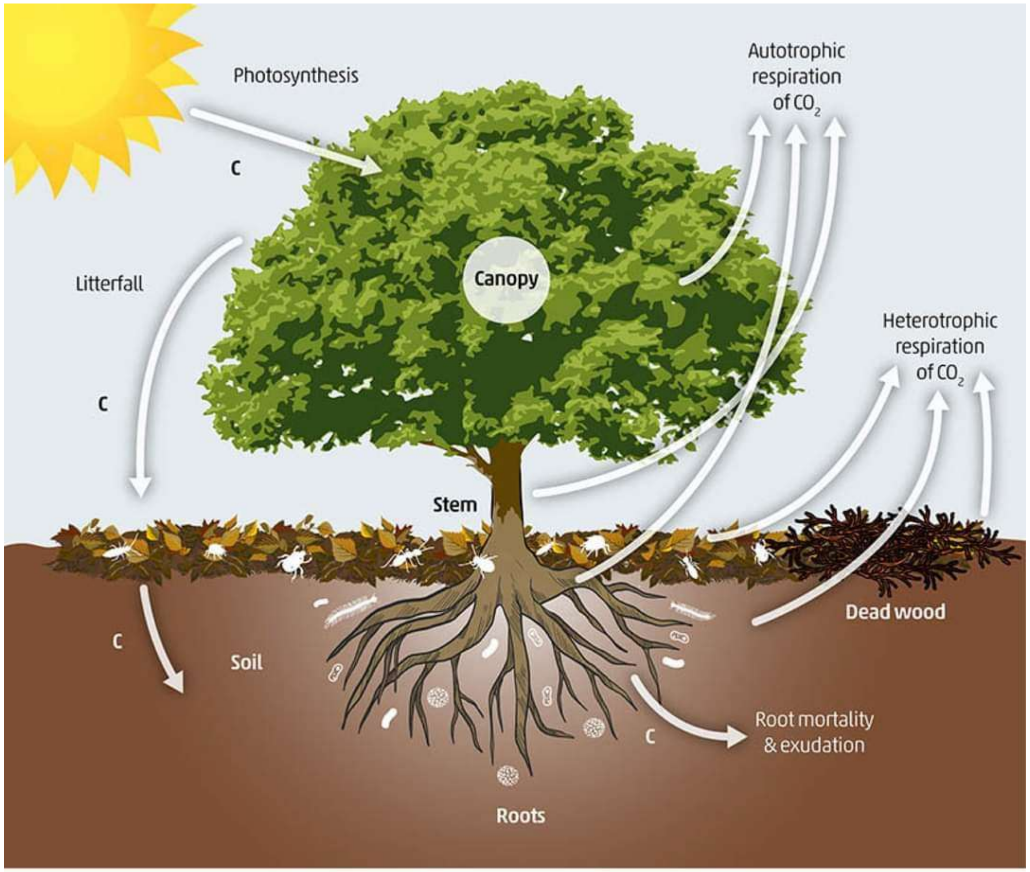


SOILS AND GLOBAL CHANGES



SOC IS DYNAMIC

- SOC stocks are large
- Input and output fluxes are large



Food and Agriculture Organization of the United Nations
GLOBAL SOIL PARTNERSHIP

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- The SOC dynamic can significantly affect the GHG balance at the country level, in particular with important LUC.

SOC IS DYNAMIC

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BUT

SOC dynamics measurements is quite challenging

QUESTIONS ?

DIFFERENT METHODS DEVELLOPED

- 2006 IPCC Guidelines for National Greenhouse Gas Inventories (in particular in volume 4)

<https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>

- **Tiers:** A tier represents a level of methodological complexity.
- **Usually three tiers are provided:**
  - Tier 1 is the basic method,
  - Tier 2 - intermediate complexity
  - Tier 3 - most demanding in terms of complexity and data requirements
- Tiers 2 and 3 are sometimes referred to as *higher tier methods* and are generally considered to be more accurate

DIFFERENT METHODS DEVELLOPED

LOW COMPLEXITY

HIGH COMPLEXITY

- **Tier 1:** emissions estimated with average emission/stock change factors for large eco-regions of the world and globally-available data. The simplest to use.
- **Tier 2 :** Similar to Tier 1 but with country specific emissions /stock change factors.
- **Tier 3 :** Based on national inventories and/or process-based models.

DIFFERENT METHODS DEVELLOPED

LOW
COMPLEXITY

- **Tier 1**
- **Tier 2**
- **Tier 3**

HIGH
COMPLEXITY

?

=

LOW
ACCURACY

- **Tier 1**
- **Tier 2**
- **Tier 3**

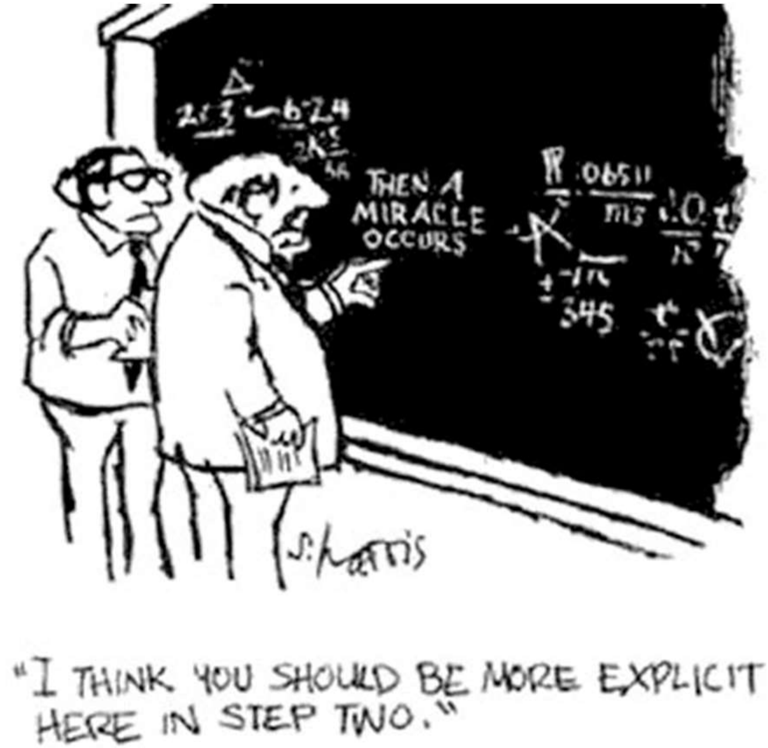
HIGH
ACCURACY

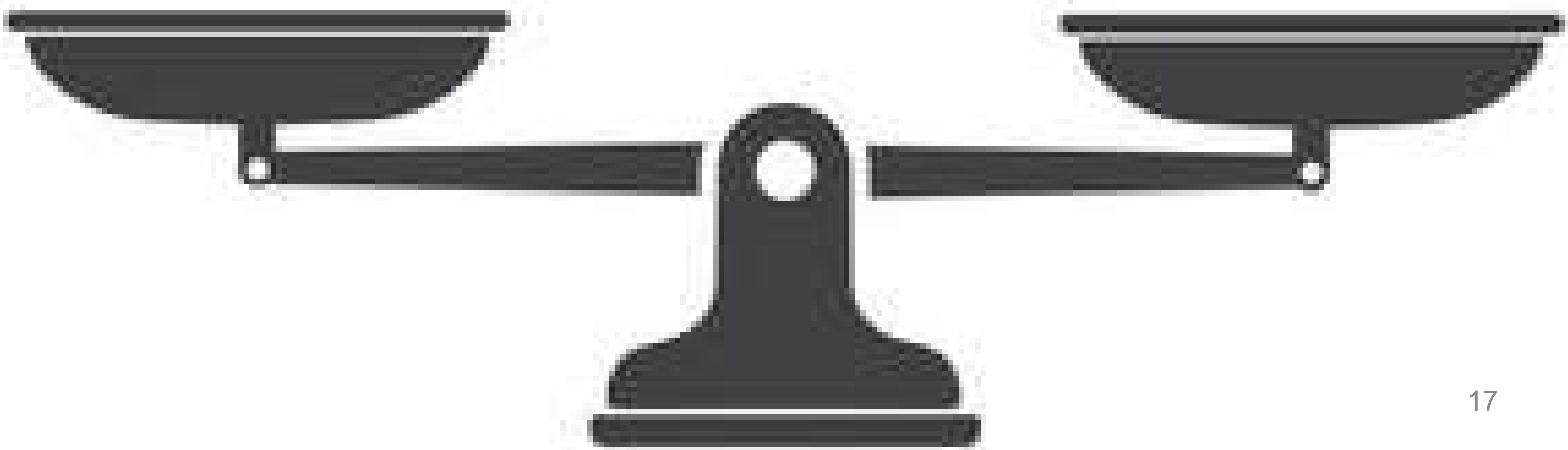
DIFFERENT METHODS DEVELLOPED

- "Good practice" is a key concept for inventory compilers to follow in preparing national greenhouse gas inventories.
- A set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that uncertainties are reduced so far as practicable.

Choose the tier approach more adapted to your situation

DIFFERENT METHODS DEVELLOPED





HOW ESTIMATE SOC CHANGE

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Eq. 2.1 *2006 IPCC GLs*

- AFOLU = Agriculture, Forestry and Other Land Use, FL = Forest Land, CL= Cropland, GL = Grassland, WL=Wetlands, SL= Settlements, OL = Other Land

HOW ESTIMATE SOC CHANGE

For a given land-use category

$$\Delta C_{LU} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Eq. 2.3 *2006 IPCC GLs*

- AB = above-ground biomass
- BB = below-ground biomass
- DW = deadwood
- LI= litter
- SO = soils
- HWP = harvested wood products

HOW ESTIMATE SOC CHANGE

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QUESTIONS ?

TWO DIFFERENT METHODS PROPOSED TO ESTIMATE C STOCK CHANGES

GAIN LOSS METHOD

$$\Delta C = \Delta C_G + \Delta C_L$$

ΔC = annual carbon stock change in the pool, tonnes C yr^{-1}

ΔC_G = annual gain of carbon, tonnes C yr^{-1}

ΔC_L = annual loss of carbon, tonnes C yr^{-1}

Eq. 2.4 *2006 IPCC GLs*

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Eq. 2.4 *2006 IPCC GLs*

STOCK DIFFERENCE METHOD

$$\Delta C = \frac{(C_{t2} - C_{t1})}{(t_2 - t_1)}$$

Δ**C** = annual carbon stock change in the pool, tonnes C yr^{-1}

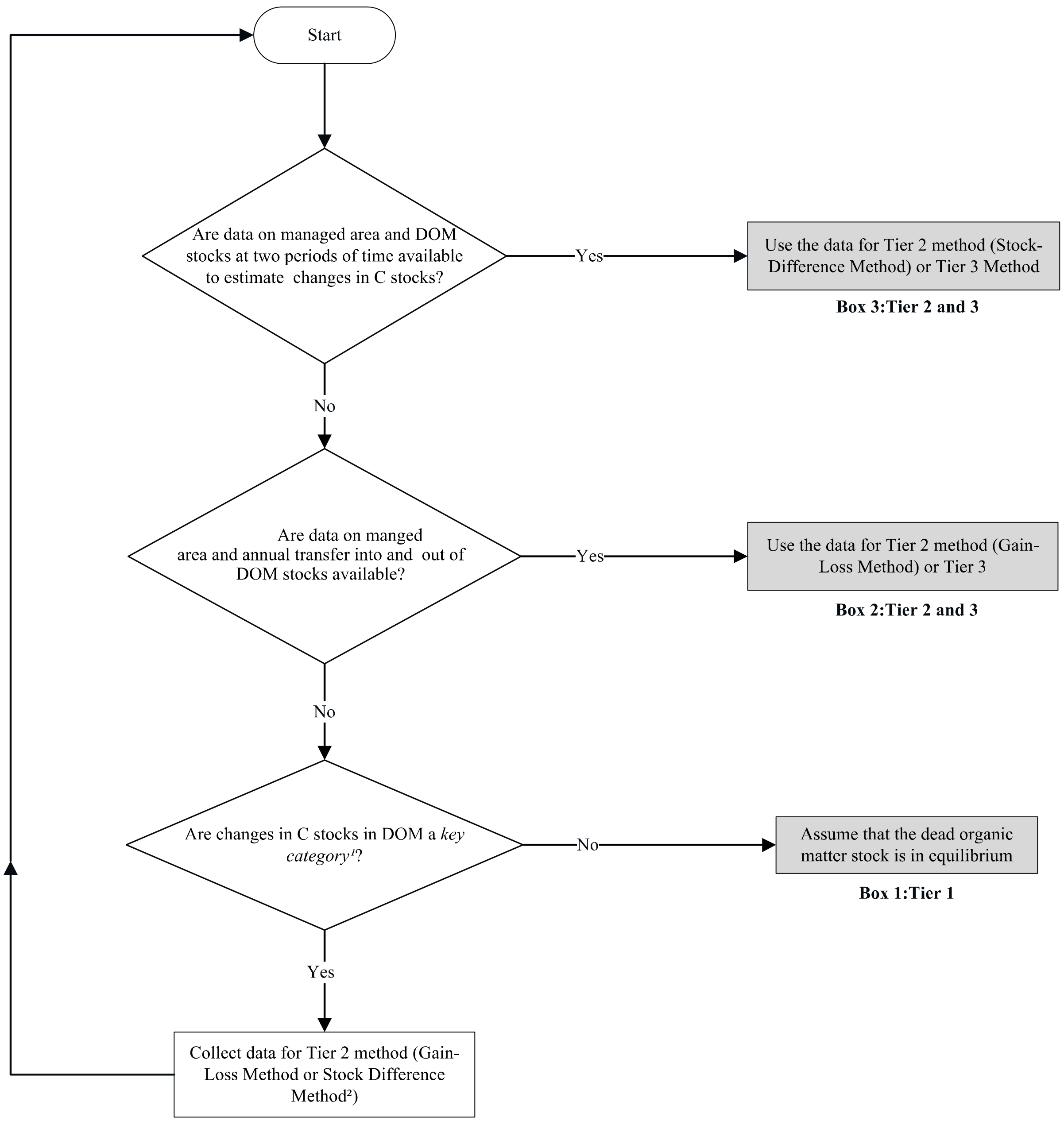
C$_{t1}$ = carbon stock in the pool at time 1, tonnes C

C$_{t2}$ = carbon stock in the pool at time 2, tonnes C

Eq. 2.5 *2006 IPCC GLs*

WHICH METHODS YOU HAVE TO USE ?

Figure 2.3 **Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in dead organic matter for a land-use category**



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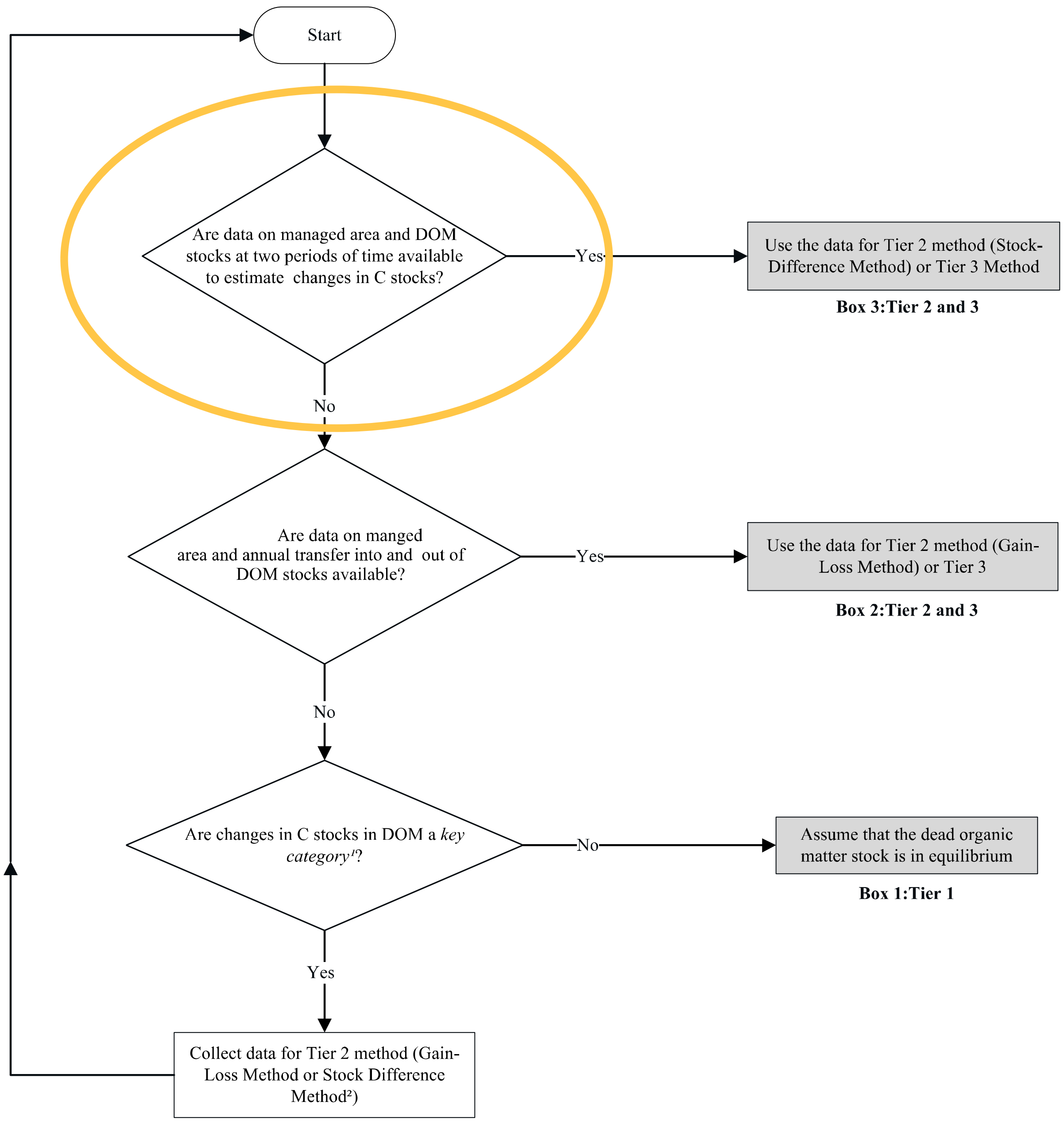

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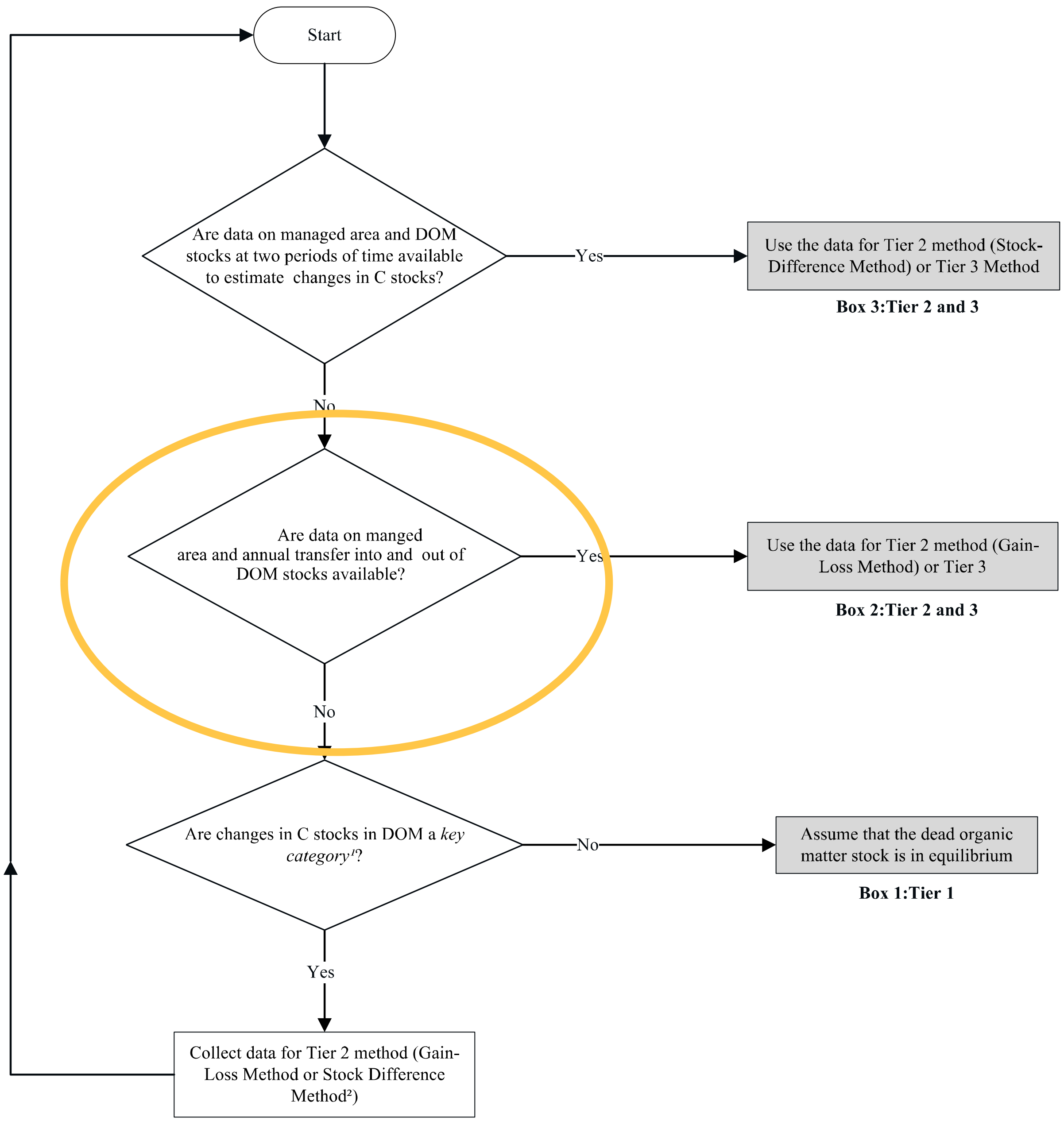

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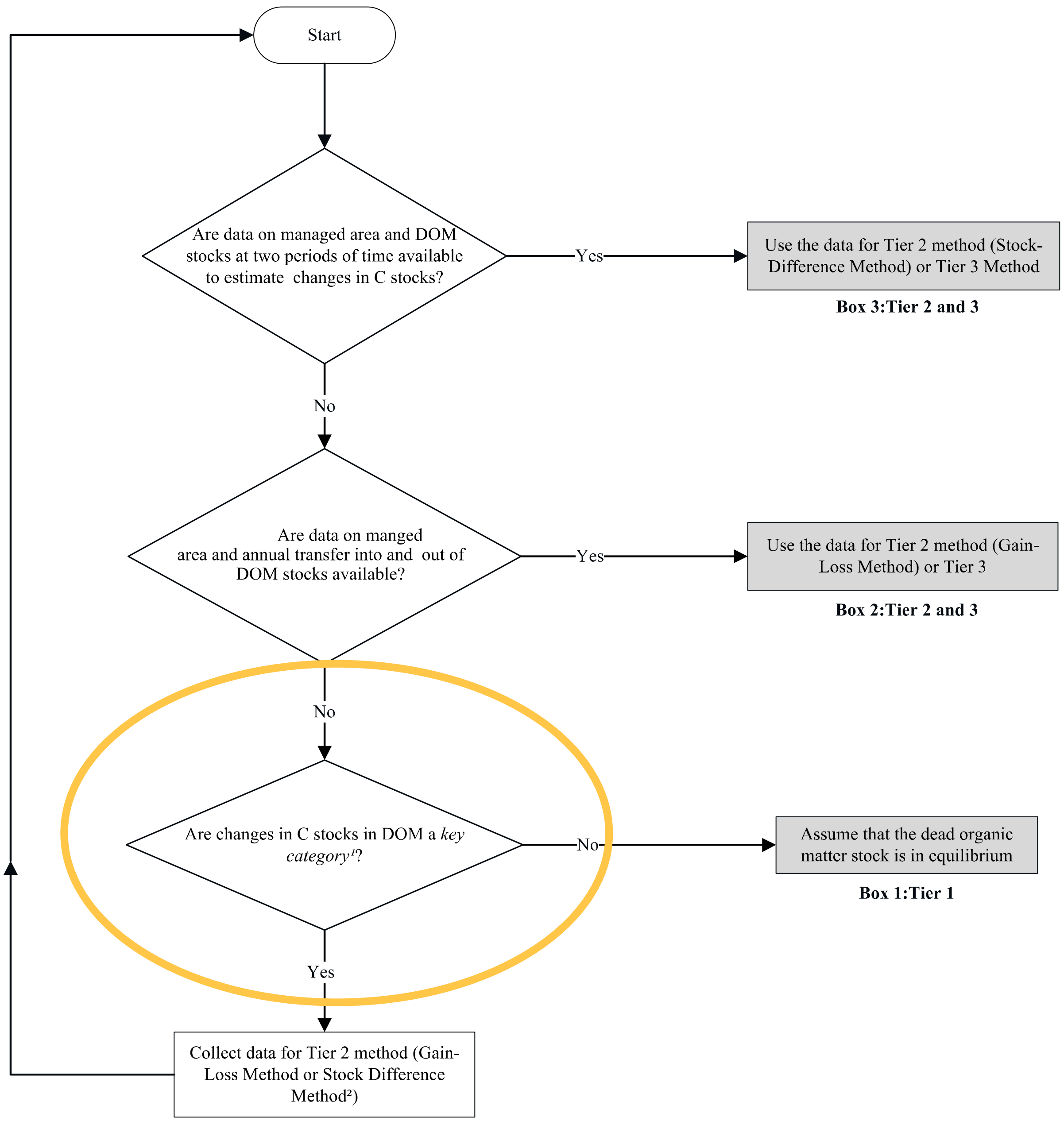


BUT DIFFERENT POOLS ALSO FOR SOIL CARBON

$$\Delta C_{Soil} = \Delta C_{Mineral} - L_{organic} + \Delta C_{inorganic}$$

Eq. 2.24 *2006 IPCC GLs*

- ΔC_{Soil}= annual change in carbon stocks in soils, tonnes C yr^{-1}
- $\Delta C_{Mineral}$= annual change in carbon stocks in mineral soils, tonnes C yr^{-1}
- $L_{organic}$ = annual loss of carbon from drained organic soils, tonnes C ha^{-1}
- $\Delta C_{Inorganic}$= annual change in inorganic carbon stocks in soils, tonnes C yr^{-1} (assumed to be 0 unless using a Tier 3 approach)

BUT DIFFERENT POOLS ALSO FOR SOIL CARBON

- For Tier 1 methods, soil organic C stocks for mineral soils are computed to a **default depth of 30 cm** because default reference soil organic C stocks and stock change factors are based on a 30 cm depth.

- For Tier 2, a different reference condition and depth can be used as described in the section on Tier 2 methods.

- **No Tier 1 or 2 methods are provided for estimating the change in soil inorganic C** stocks due to limited scientific data for derivation of stock change factors; thus, the net flux for inorganic C stocks is assumed to be zero.

- Tier 3 methods could be developed to estimate changes in the stock of inorganic carbon in mineral or organic soils.

BUT DIFFERENT POOLS ALSO FOR SOIL CARBON

Table 2.3
Default reference (under native vegetation) soil organic C stocks (SOC_{REF}) for mineral soils (tonnes C ha^{-1} in 0-30 cm depth)

Climate region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetland soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	
Tropical montane	88*	63*	34*	NA	80*	

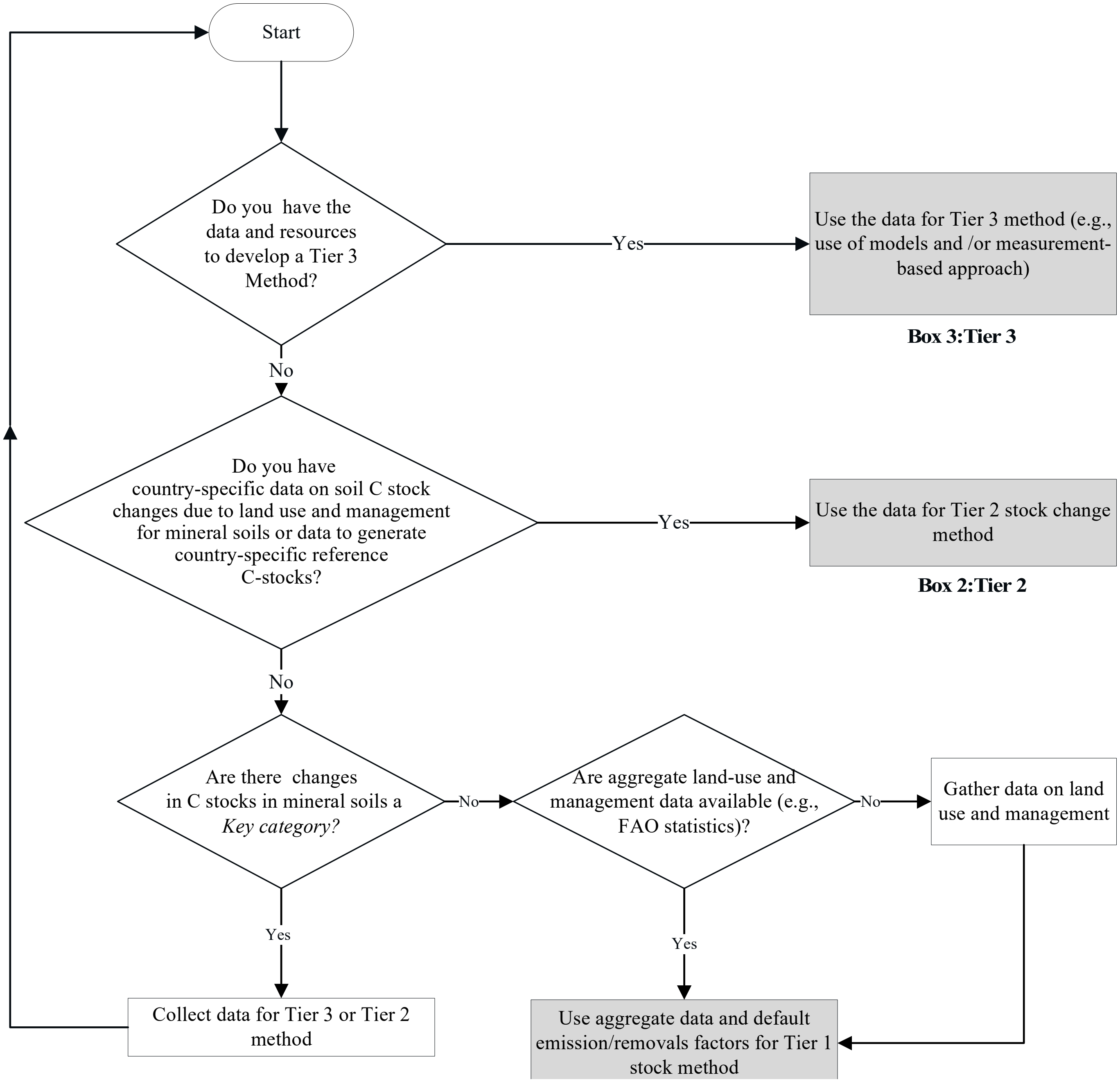
IPCC GLs

BUT DIFFERENT POOLS ALSO FOR SOIL CARBON

- It is possible that compilers will use **different tiers** to prepare estimates for mineral soils, organic soils, biochar amendments and soil inorganic C, depending on the availability of resources.
- Thus, stock changes are discussed separately for organic carbon in mineral and organic soils and for inorganic C pools (Tier 3 only).

WHICH TIERS METHOD TO USE ?

Figure 2.4 **Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in mineral soils by land-use category.**



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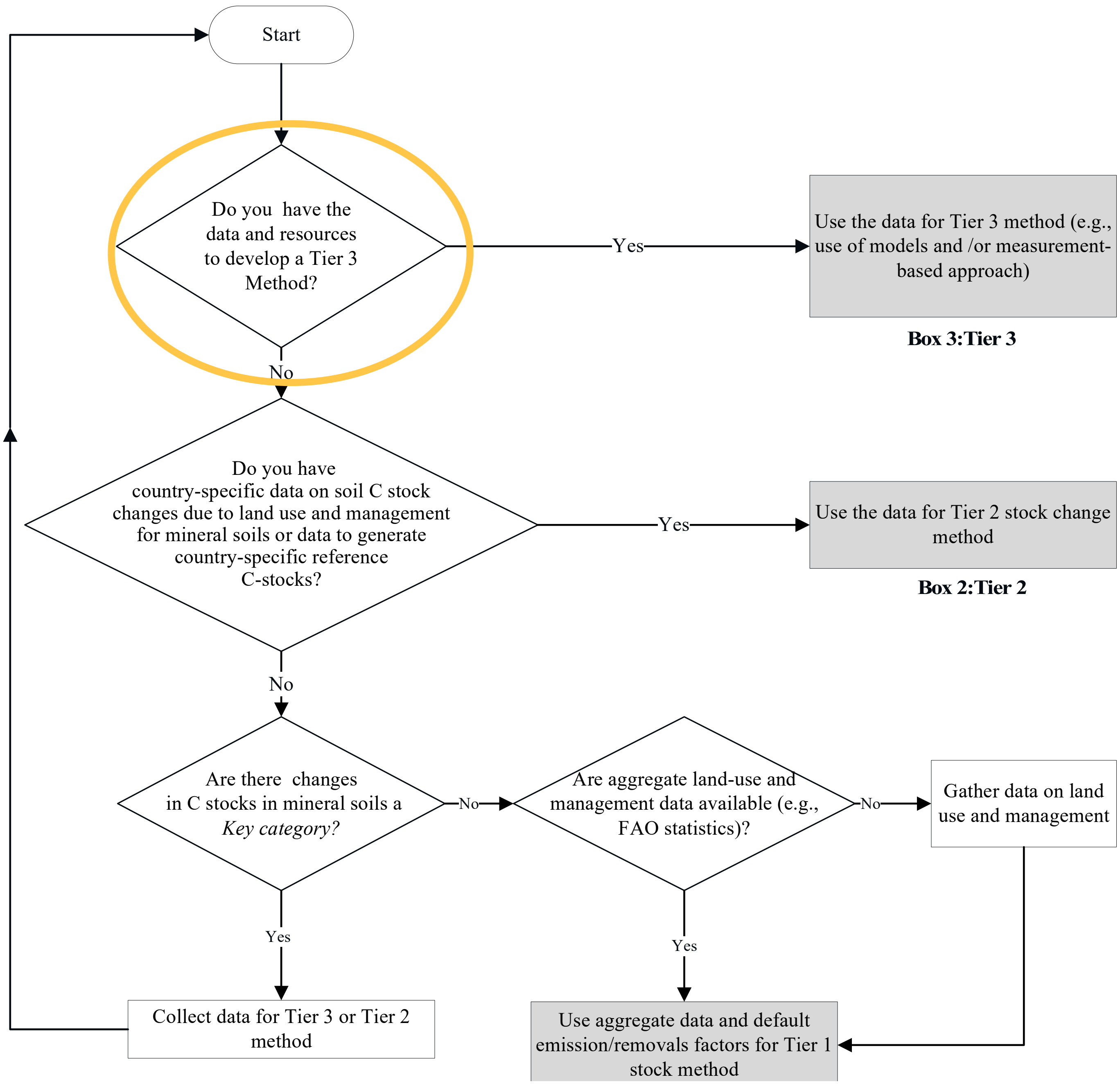

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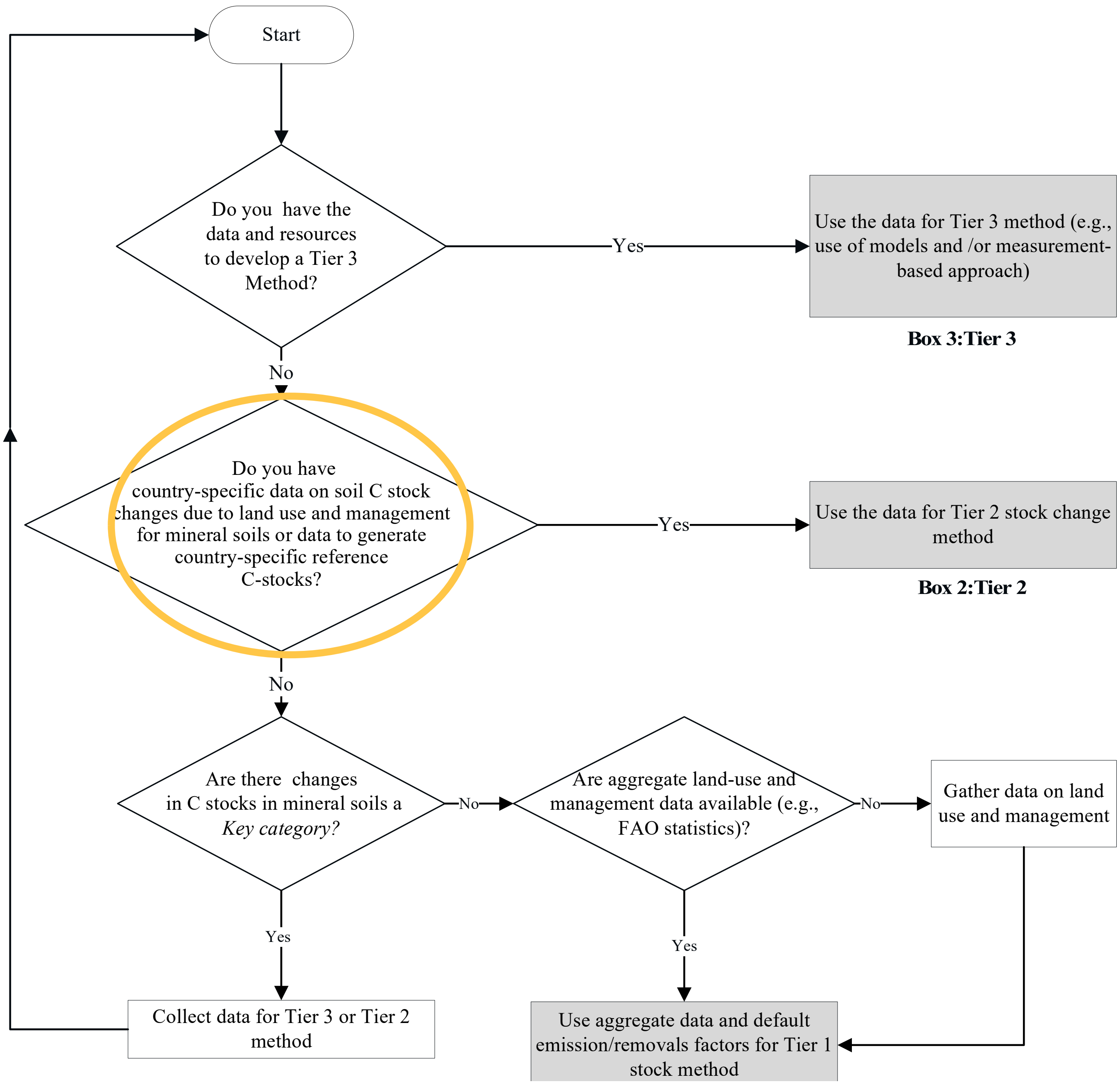

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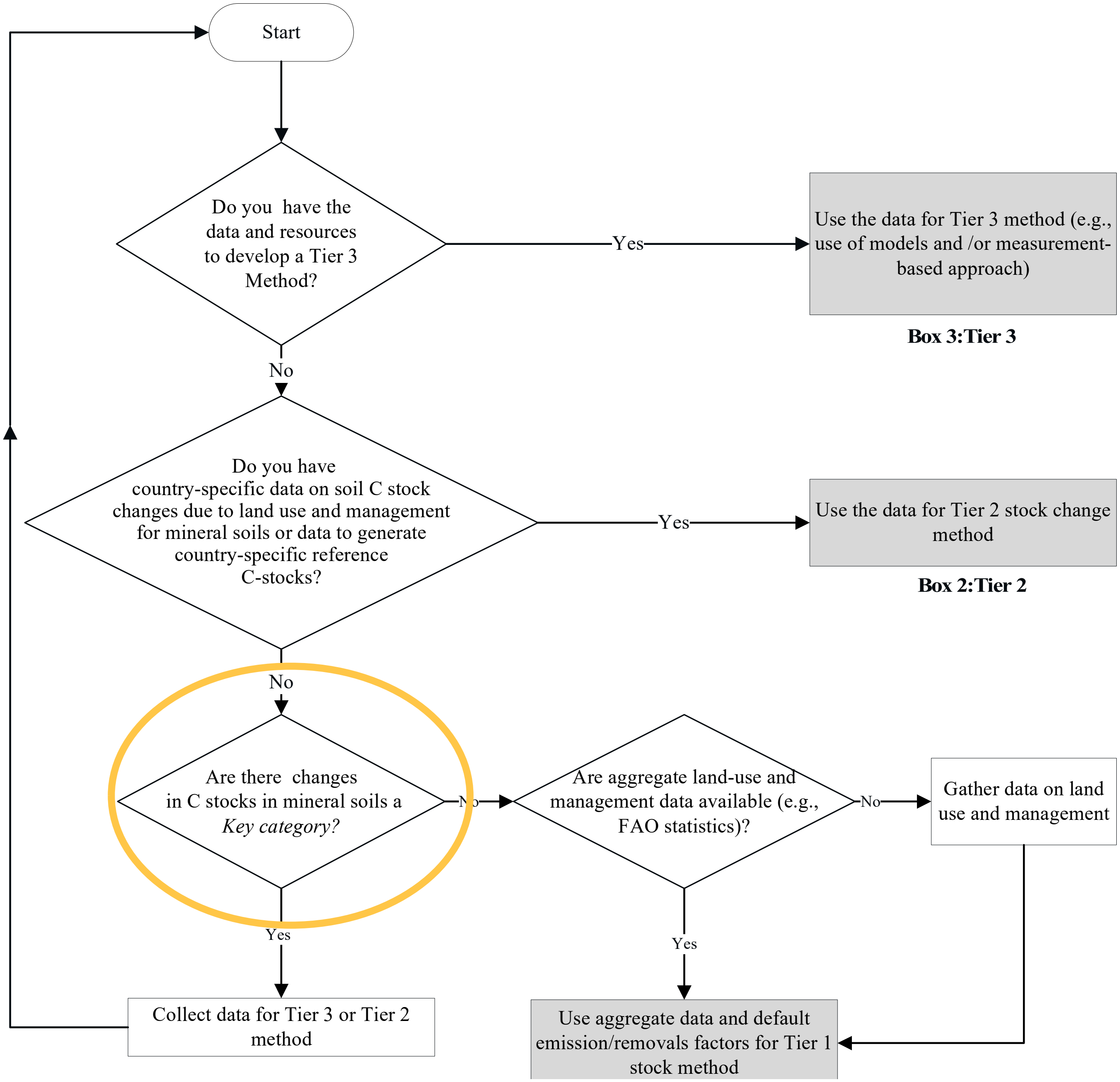

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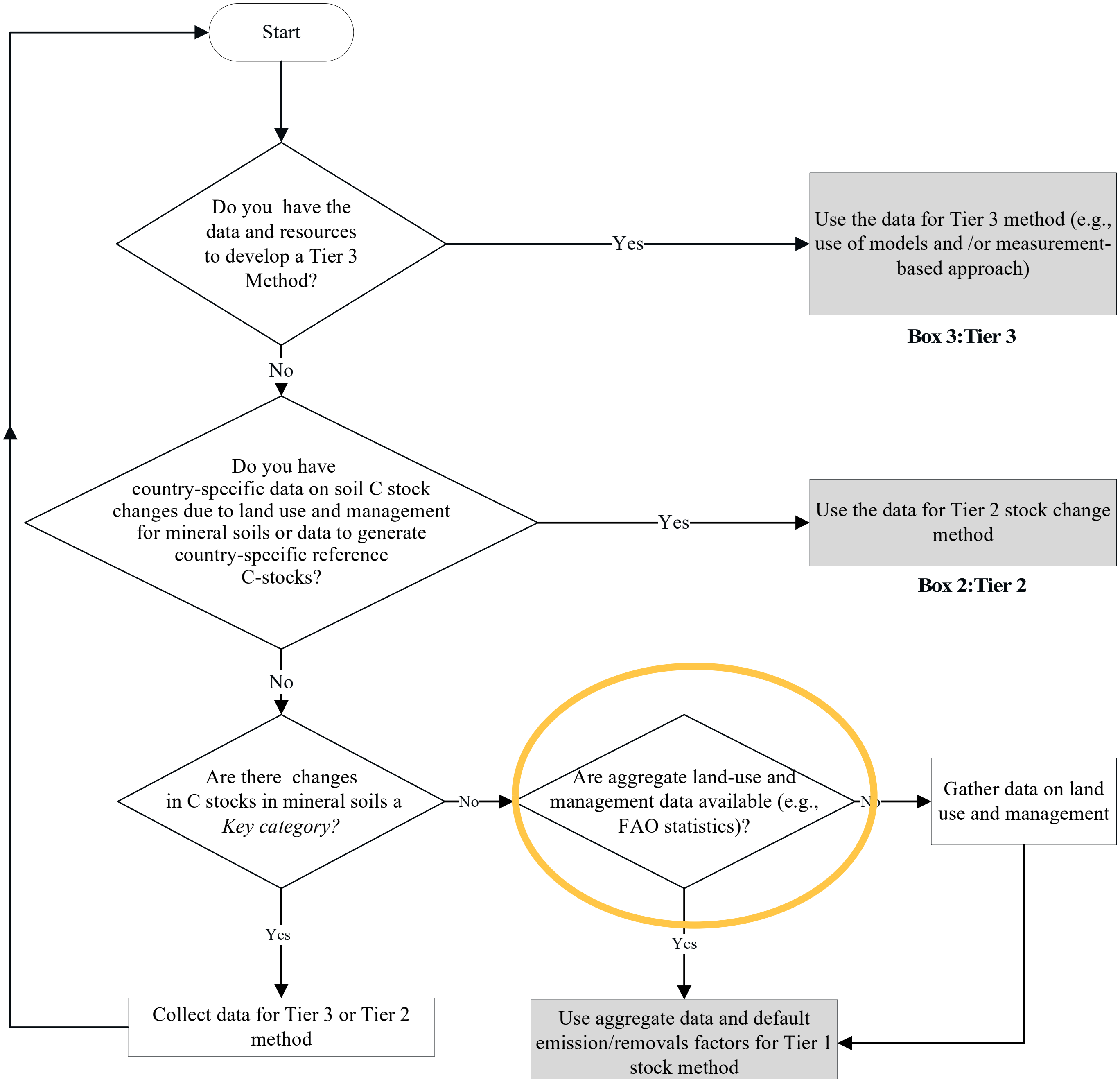
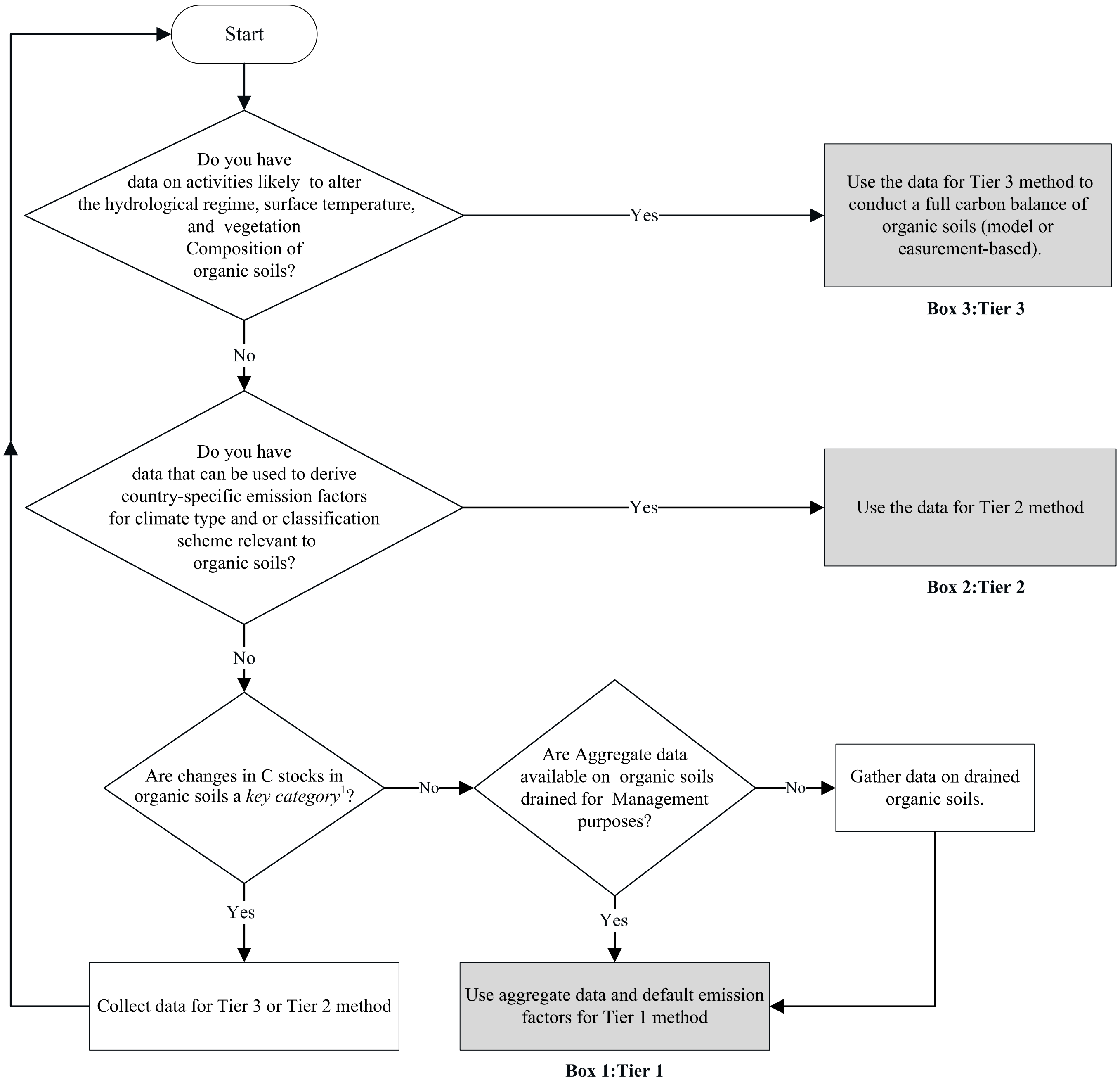


WHICH TIERS METHOD TO USE ?

Figure 2.5 **Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in organic soils by land-use category**



MOVING TOWARDS A STOCK DIFFERENCE METHOD

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-t)})}{D}$$

Eq. 2.25 *2006 IPCC GLs*

- $\Delta C_{Mineral}$= annual change in organic C stocks in mineral soils, tonnes C yr^{-1}
- SOC_0 = mineral soil organic C stock ($SOC_{Mineral}$) in the last year of an inventory time period, tonnes
- $SOC_{(0-t)}$ = mineral soil organic C stock ($SOC_{Mineral}$) at the beginning of the inventory time period, tonnes
- T = number of years over a single inventory time period, yr
- D = Time dependence of mineral soil organic C stock change factors which is the default time period for transition between equilibrium SOC values, yr.

MOVING TOWARDS A STOCK DIFFERENCE METHOD

$$SOC_{Mineral} = \sum_{c,s,i}(SOC_{REF_{c,s,i}} \times F_{LU_{c,s,i}} \times F_{MG_{c,s,i}} \times F_{I_{c,s,i}} \times A_{c,s,i})$$

Eq. 2.25 *2006 IPCC GLs*

- c = represents the climate zones included in the inventory , s = represents the soil types included in the inventory, i = represents the set of management systems included in the inventory.
- $SOC_{Mineral}$ = total mineral soil organic C stock at a defined time, tonnes C
- $SOC_{REF_{c,s,i}}$ = the soil organic C stock for mineral soils in the reference condition, tonnes C ha^{-1}
- $F_{LU_{c,s,i}}$ = stock change factor for mineral soil organic C land-use systems or sub-systems for a particular land-use, dimensionless
- $F_{MG_{c,s,i}}$ = stock change factor for mineral soil organic C for management regime, dimensionless
- $F_{I_{c,s,i}}$ = stock change factor for mineral soil organic C for the input of organic amendments, dimensionless
- $A_{c,s,i}$ = land area of the stratum being estimated, ha

QUESTIONS ?

AND FOR SOC USING TIER 1?

- For mineral soils, the stock change factor method is based on **changes in soil C stocks** ($\Delta C_{Mineral}$) over a finite period of time of 20 years.

- The change in organic C stock in mineral soil ($SOC_{Mineral}$) is computed by calculating the organic C stock remaining after a management change relative to the organic C stock in **a reference condition** and summing this change over all climate zones, soil types and management practices included in the inventory.

- The soil organic C stock present under the reference condition for the Tier 1 method is defined as that in non-degraded, unimproved lands under native vegetation.

AND FOR SOC USING TIER 1?

- The following assumptions are made:
  - Over time, soil organic C stock reaches a spatially-averaged, stable **value specific to the soil, climate, land-use and management practices;**
  - Soil organic C stock change during the transition to a new equilibrium SOC occurs in a **linear fashion** over a period of 20 years.

AND FOR SOC USING TIER 2?

- A Tier 2 method is **an extension of the Tier 1** method that allows an inventory to incorporate country-specific data.
- It is **good practice for countries to use a Tier 2 method, if possible**, even if they are only able to better specify certain components of the Tier 1 method.
- Country-specific data can be used to improve four components when applying the Tier 1 equations for estimating stock changes in mineral soils.
- Inventory compilers can choose to derive **specific values for all of these components, or any subset**, which would be combined with default values provided in the Tier 1 method to complete the inventory calculations using.

AND FOR SOC USING TIER 2?

- Countries that have **detailed soil classifications and climatic data** have the option of developing country-specific classifications.
- Deriving country-specific reference condition soil C stocks (SOC_{REF}) is another possibility for improving an inventory using a Tier 2 method.
- Country-specific stocks can be estimated from soil measurements, for example, as part of a country's soil survey.
- It is important that reliable taxonomic descriptions be used to group soils into categories.

AND FOR SOC USING TIER 3?

- Tier 3 approaches for soil C involve **the development of an advanced estimation system** that will typically better capture annual variability in fluxes, unlike Tier 1 and 2 approaches that mostly assume a constant annual change in C stocks over an inventory time period based on a stock change factor.

- Soil C stocks typically **do not exist in an absolute equilibrium** state or change in a linear manner through a transition period (assumptions behind Tier 1 and Tier 2)

- Tier 3 approaches can address **this non-linearity** using more advanced models than Tiers 1 and 2 methods, and/or by developing a measurement-based inventory with a monitoring network.

AND FOR SOC USING TIER 3?

- Tier 3 modelling approaches are capable of addressing the influence of land use and management with a dynamic representation of environmental conditions.
- The impact of land use and management on soil C stocks can vary as environmental conditions change, and such changes are not captured in lower Tiers, which may create biases in those results.
- Tier 3 methods can also include lateral flows of C associated with erosion and deposition.

Tier 3 approaches more accurate

AND FOR SOC USING TIER 3?

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- The impact of land use and management on soil C stocks can vary as environmental conditions change, and such changes are not captured in lower Tiers, which may create biases in those results.
- Tier 3 methods can also include lateral flows of C associated with erosion and deposition.

Tier 3 approaches more accurate when calibrated to the range of environmental conditions, soil properties and management practices to which the model will subsequently be applied

QUESTIONS ?

THE SOIL MASS EQUIVALENT DIFFICULTY

- Soil carbon stock estimates may be improved when deriving country-specific factors for F_{LU} and F_{MG}, by **expressing carbon stocks on a soil-mass equivalent basis** rather than a soil-volume equivalent (i.e. fixed depth) basis.

$$SOC = OCC \times BD \times (1-G) \times D$$

SOC= Soil organic stocks
OCC = the organic carbon content
BD = the bulk density
G = the gravel content or the coarse fragments and/or segregated ice content
D = the layer thickness (m)

THE SOIL MASS EQUIVALENT DIFFICULTY

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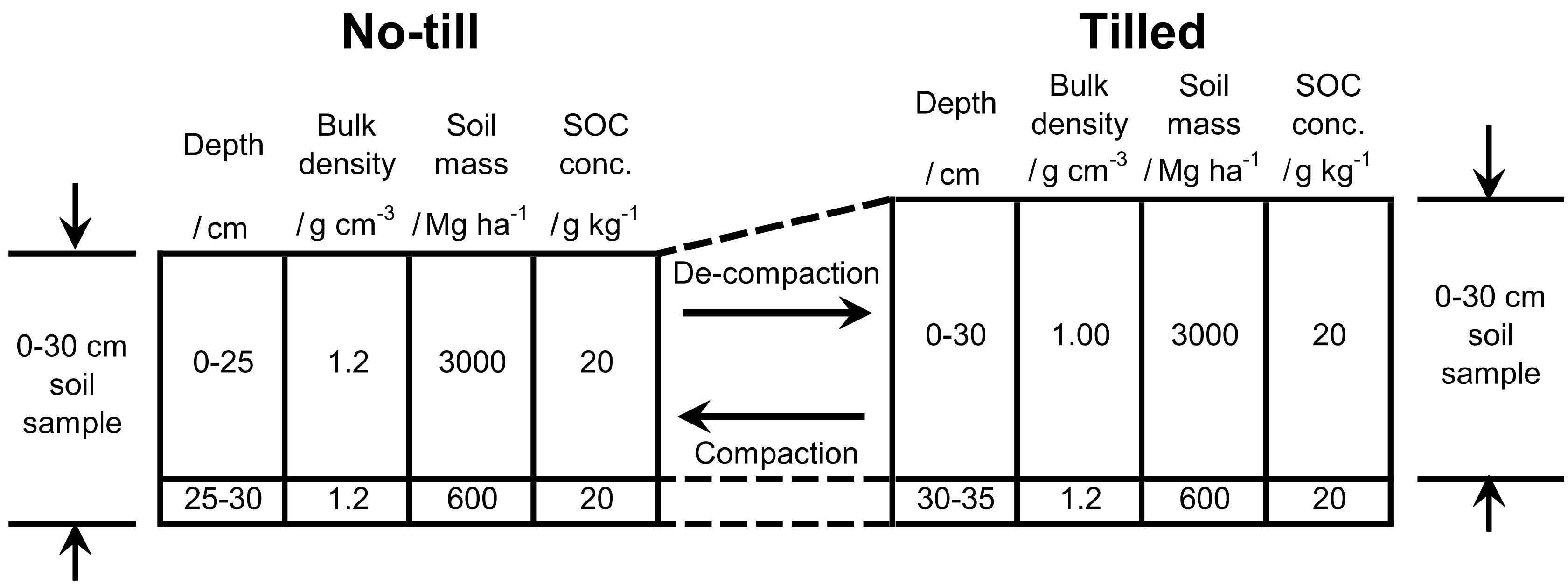

	No-till (compacted)	Tilled (de-compacted)	% error
SOC (kg ha^{-1}) in 30 cm depth layer	72 000	60 000	-16.7
kg SOC ha^{-1} in 3000 Mg soil mass layer	60 000	60 000	0
kg SOC ha^{-1} in 3600 Mg soil mass layer	72 000	72 000	0

Wendt & Hauser et al 2013

THE SOIL MASS EQUIVALENT DIFFICULTY

- **Soil mass** to a certain soil depth **changes** in response to altered management practices.

- **Soil bulk density** may be **affected** differently by particular **management practices** within a given land.

- Where the soil bulk density changes, the comparison of the soil carbon stocks at the same depth introduces changes to soil carbon stocks as a direct consequence of changes in soil bulk density.

THE SOIL MASS EQUIVALENT DIFFICULTY

- With a management induced **change in soil bulk density**, it is possible to calculate a **change in soil carbon stock to a fixed depth in the absence of any change in soil carbon content.**

- Therefore, it is **more robust and rigorous** to calculate soil carbon stock change on an equivalent mass basis rather than on a fixed-depth basis.

- It is important to realise that **comprehensive data** of soil carbon concentration and soil bulk density **would be required**.

AN EXAMPLE OF A TIER 3 APPLICATION

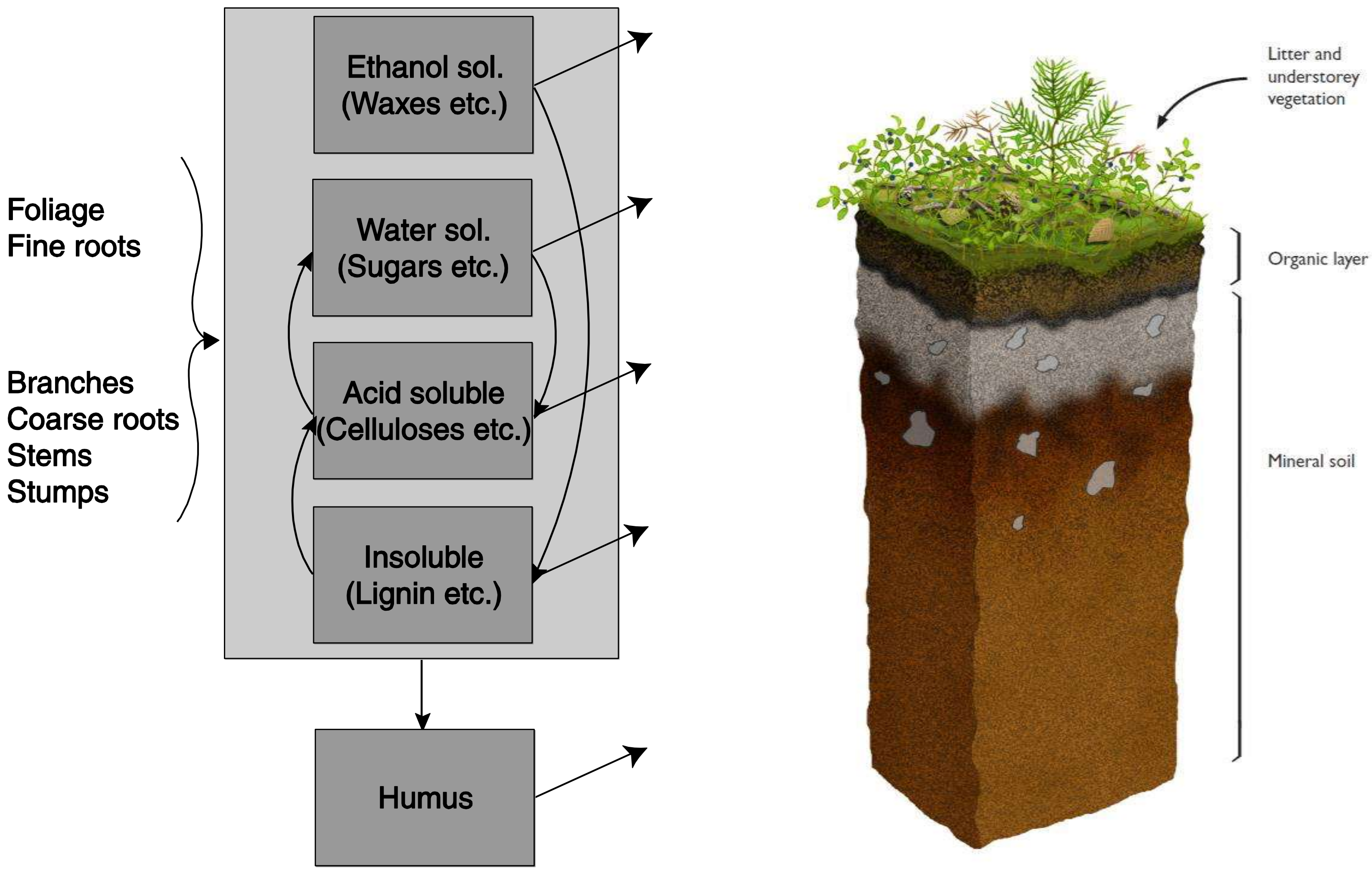

Figure 1_App_6e The structure of the Yasso07 soil carbon model (left) and an illustration of the soil profile (right)

AN EXAMPLE OF A TIER 3 APPLICATION

- A specific set of parameters developed for Scandinavia

Parameter	Value	Unit	Meaning
aA	-0.517	a^{-1}	decomposition rate of A
aW	-3.552	a^{-1}	decomposition rate of W
aE	-0.346	a^{-1}	decomposition rate of E
aN	-0.266	a^{-1}	decomposition rate of N
p1	0.0449	.	mass flow from W to A
p2	0.0029	.	mass flow from E to A
p3	0.978	.	mass flow from N to A
p4	0.637	.	mass flow from A to W
p5	0.312	.	mass flow from E to W
p6	0.0187	.	mass flow from N to W
p7	0.0225	.	mass flow from A to E
p8	0.0117	.	mass flow from W to E
p9	0.001	.	mass flow from N to E
p10	0.336	.	mass flow from A to N
p11	0.042	.	mass flow from W to N
p12	0.0899	.	mass flow from E to N
b1	0.0895	C^{-1}	temperature dependence parameter
b2	-0.0023	C^{-2}	temperature dependence parameter
y	-2.94	m^{-1}	precipitation dependence parameter
ω_1	-0.081	$a^{-1}m^{-1}$	precipitation induced leaching (Europe)
pH	0.0015	10^{-3}	mass flow from A,W,E,N to humus
aH	-0.00024	10^{-3} a^{-1}	humus decomposition coefficient
phi_1	-0.539	cm^{-1}	size dependence parameter
phi_2	1.186	cm^{-2}	size dependence parameter
r	-0.263	.	size dependence parameter

AN EXAMPLE OF A TIER 3 APPLICATION

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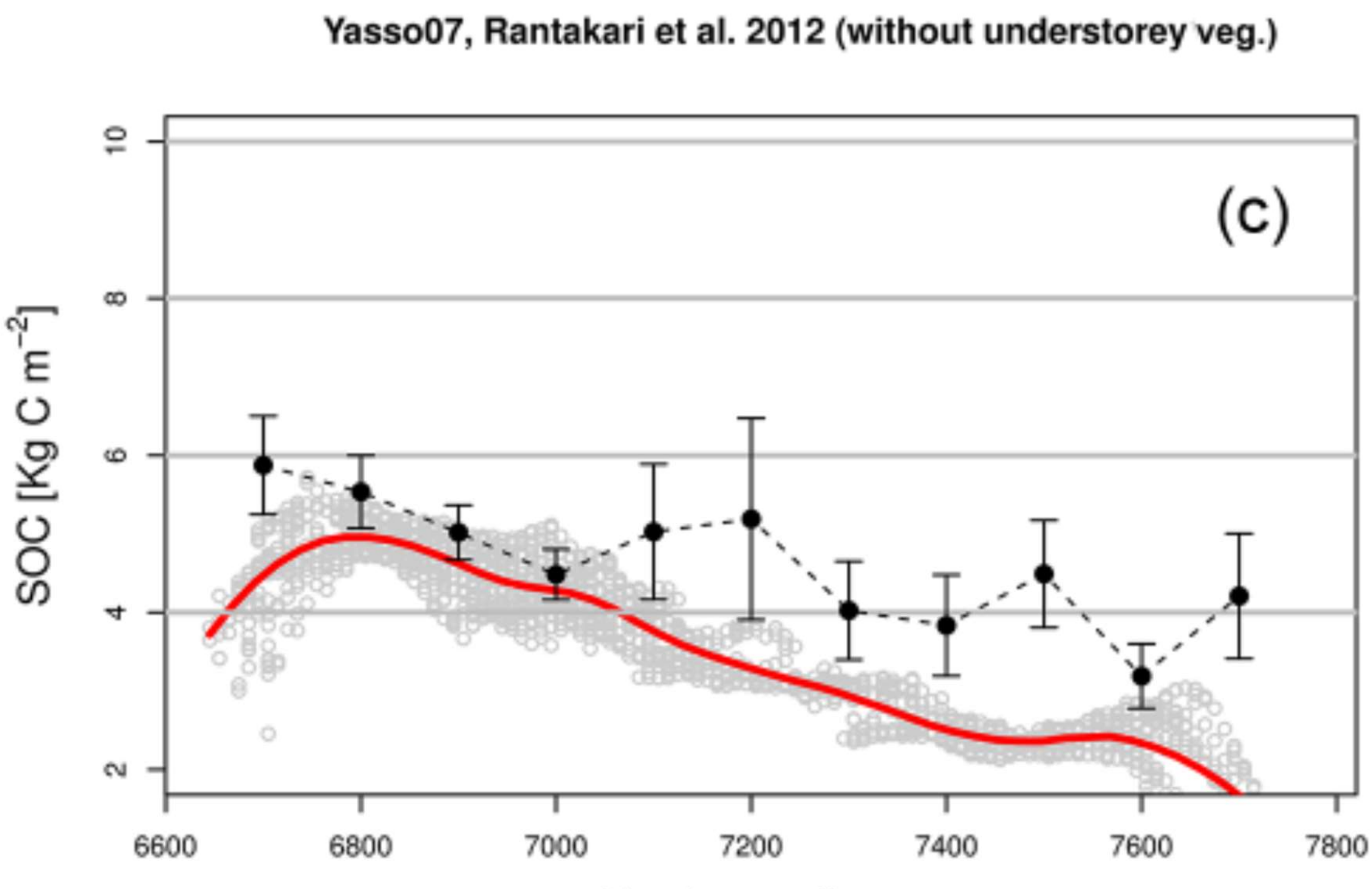
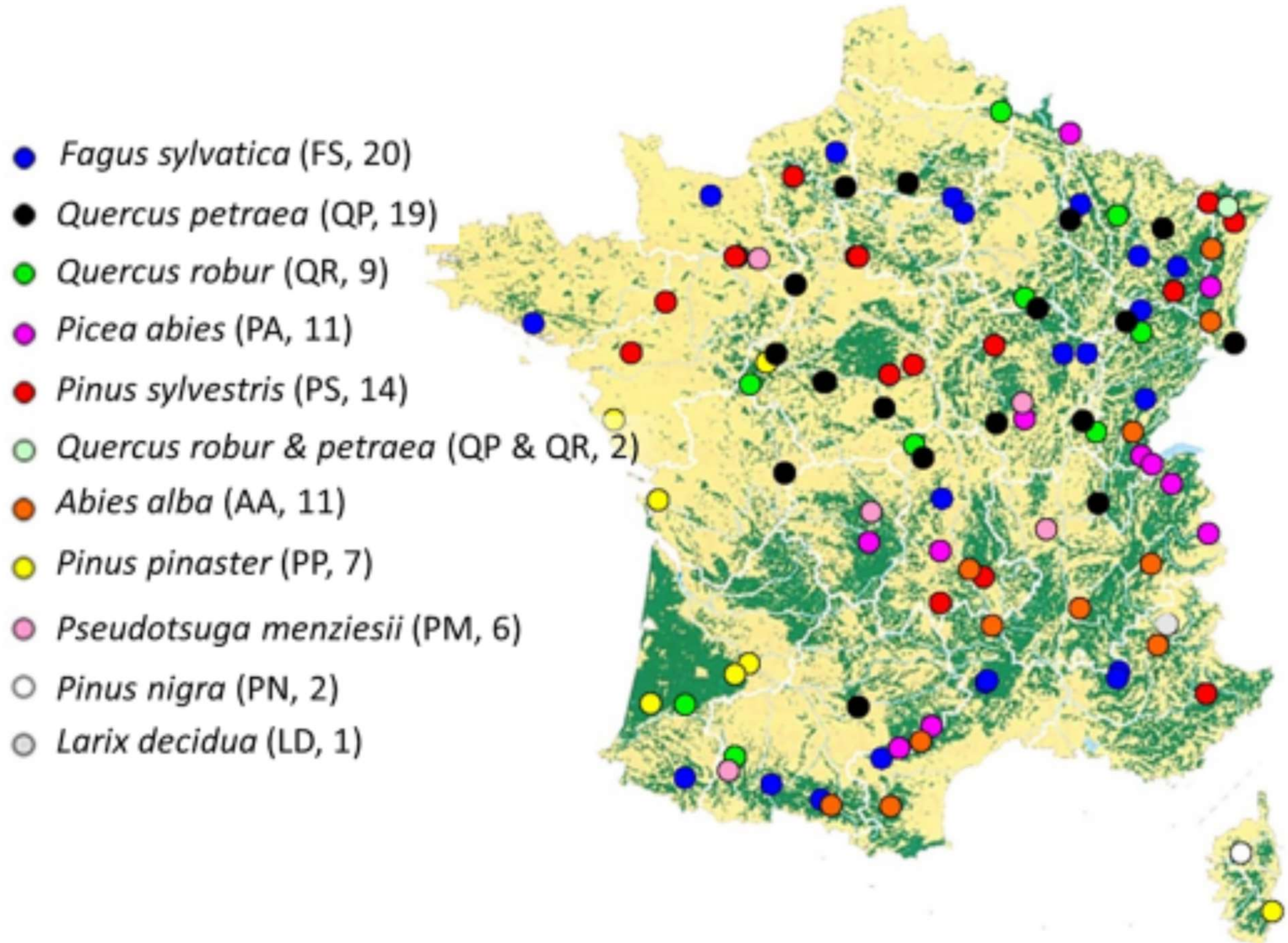


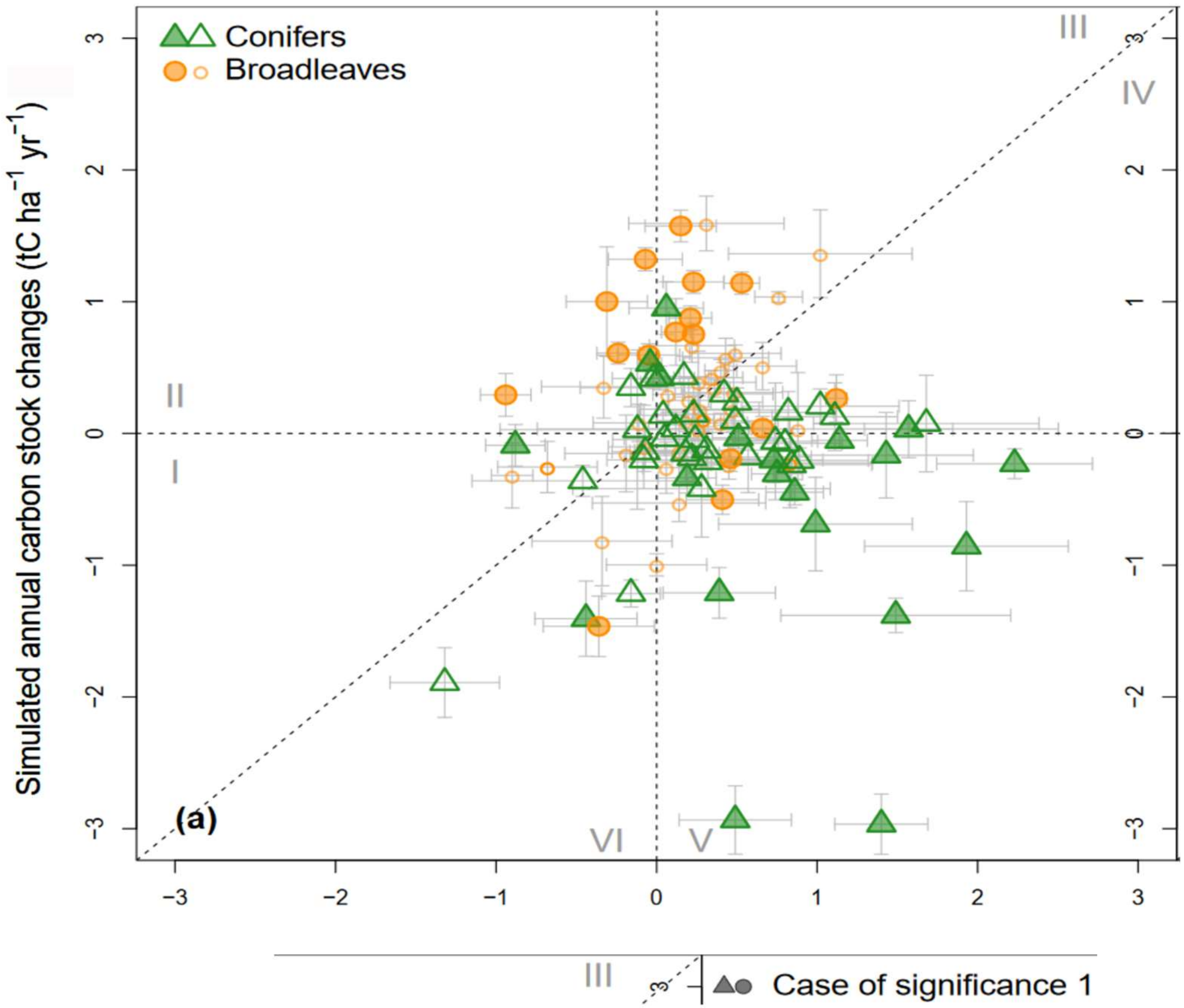
Lehtonen et al., 2016

AN EXAMPLE OF A TIER 3 APPLICATION



Mao et al 2019

AN EXAMPLE OF A TIER 3 APPLICATION



Mao et al 2019

AN EXAMPLE OF A TIER 3 APPLICATION

- The use of a Tier 3 approach in the context where it was developed is useful and probably more accurate than Tier 1 or 2 estimate.

- But when applied outside the considered context results are weak and in that case using a Tier 3 approach without a set of parameters adapted to pedo-climatic conditions may lead to important mistakes.

UNCERTAINTY SOURCES IN TIERS 2 AND 3

- Model-related uncertainty, i.e. the uncertainty related to the model used, stemming from the estimation of the parameters of this model and residual variability around model.
- Sampling variability and measurement errors in input data
- The uncertainty of transferring the model to situations not used for estimation of the parameters.
- Magnitudes of the effects of the first and second sources should be reported with the model, the latter can be reduced

AIMING A TIER 3 APPROACH ADVANTAGES

- Tier 3 methods afford the opportunity to develop a measurement-based inventory using a similar monitoring network as needed for model evaluation.

- But a considerably larger sampling density is needed to minimise uncertainty, and to represent all management systems and associated land-use changes, across all climatic regions and major soil types.

- Measurement networks can be based on soil sampling at benchmark sites or flux tower networks.

THANKS TO ALL CO-AUTHORS AND FUNDING AGENCIES AND THANK YOU FOR YOUR ATTENTION!