Food and Agriculture Organization of the United Nations

The Global Soil Organic Carbon Sequestration Potential Map

(GSOCseq)

Isabel Luotto
Guillermo Peralta

GLOBAL SOIL PARTNERSHIP

The Global Soil Partnership (GSP)

Was established in December 2012 with the main aim of:

1. creating a mechanism to foster strong partnerships and collaboration to place soils on the global agenda;
2. promoting Sustainable Soil Management (SSM);
3. improving the governance of soils.

Find out more about the GSP and its many activities and projects here:
http://www.fao.org/global-soil-partnership/en/

The Global Soil Partnership (GSP) in numbers:

10 years of GSP!

8 regional partnerships, over **370** partners worldwide

160 focal points appointed directly by UN's Food and Agriculture Organization FAO member countries

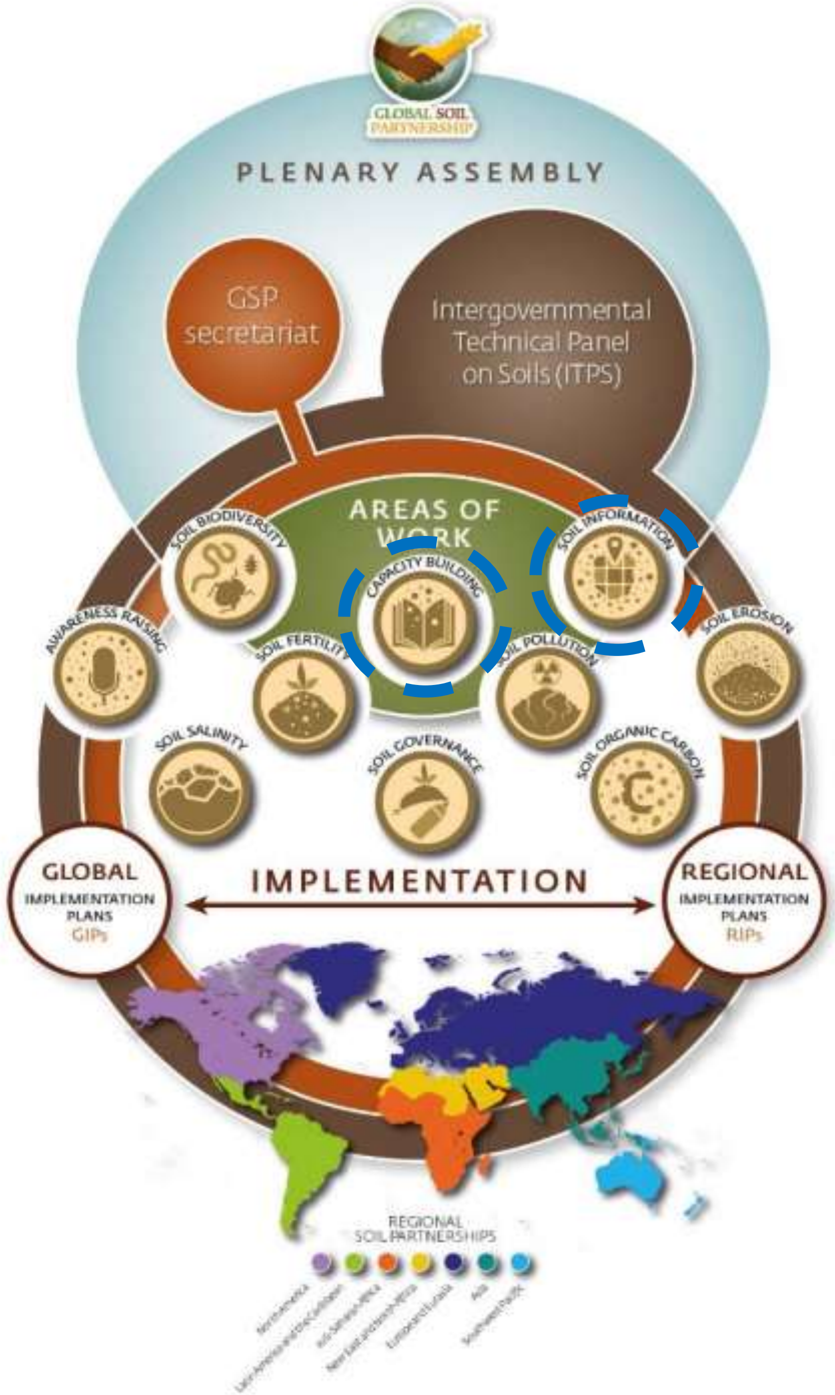
7 International Networks

Check out the main **achievements of the GSP** in this 10 year timeline!

https://www.fao.org/3/cc0212en/cc0212en.pdf

As well as the GSP Brochure!

https://www.fao.org/documents/card/en/c/cc0921en



PLENARY ASSEMBLY
GSP secretariat
Intergovernmental Technical Panel on Soils (ITPS)
AREAS OF WORK
SOIL BIODIVERSITY
CAPACITY BUILDING
SOIL INFORMATION
AWARENESS RAISING
SOIL FERTILITY
SOIL POLLUTION
SOIL EROSION
SOIL SALINITY
SOIL GOVERNANCE
SOIL ORGANIC CARBON
GLOBAL IMPLEMENTATION PLANS GIPs
IMPLEMENTATION
REGIONAL IMPLEMENTATION PLANS RIPs
REGIONAL SOIL PARTNERSHIPS

GSP - area of work:
Soil Data and Information

Soil Data is essential for…

- Global challenges, e.g. Earth-System **Models**
- National and regional data-driven **policy-making**
- Field operations, e.g. to optimize **fertilizer** and **pesticide applications**

However…

Soil Data is…

- **Not harmonized**
- **Not updated** regularly
- **Fragmented** among and within Institutions

GSP - area of work:
Soil Data and Information

Global Data Products	System Development	Capacity Development	Capacity Development	Publications
4	7	60	1200+	12
36 Map Layers	National Soil Information Systems (TCP)	Training Workshops	National Experts	Key Publications
Country Driven	Digital Transformation	DSM, Product Oriented	Large Expert Network	Technical, Scientific

Capacity Development

Capacity Development

1200+	60+
National Experts	Training Workshops

140+ Countries
All GSP Regions

GloSIS: Country-driven Global Data Products

Of the countries, by the countries, for the countries!

GSOCmap *V1.0 (2017) >> V1.5 (2019) >> V.1.5 (2020) >> V1.6 (2022)*
Global Soil Organic Carbon Map

GSOCseq *V1.0 (2021) >> v1.1 (2022)*
Global Soil Organic Carbon Sequestration Potential Map

GSASmap *V1.0 (October 2021)*
Global Salt Affected Soils Map

GBSmap *V1.0 (May 2022 by INBS)*
Global Black Soil Distribution Map

GSERmap PHASE I PHASE II
Global Soil Erosion Map

GSNmap PHASE I PHASE II
Global Soil Nutrient Map

Why **GSOCseq?**

Following FAO members request, Global Soil Partnership (GSP) has started the GSOCseq initiative to:

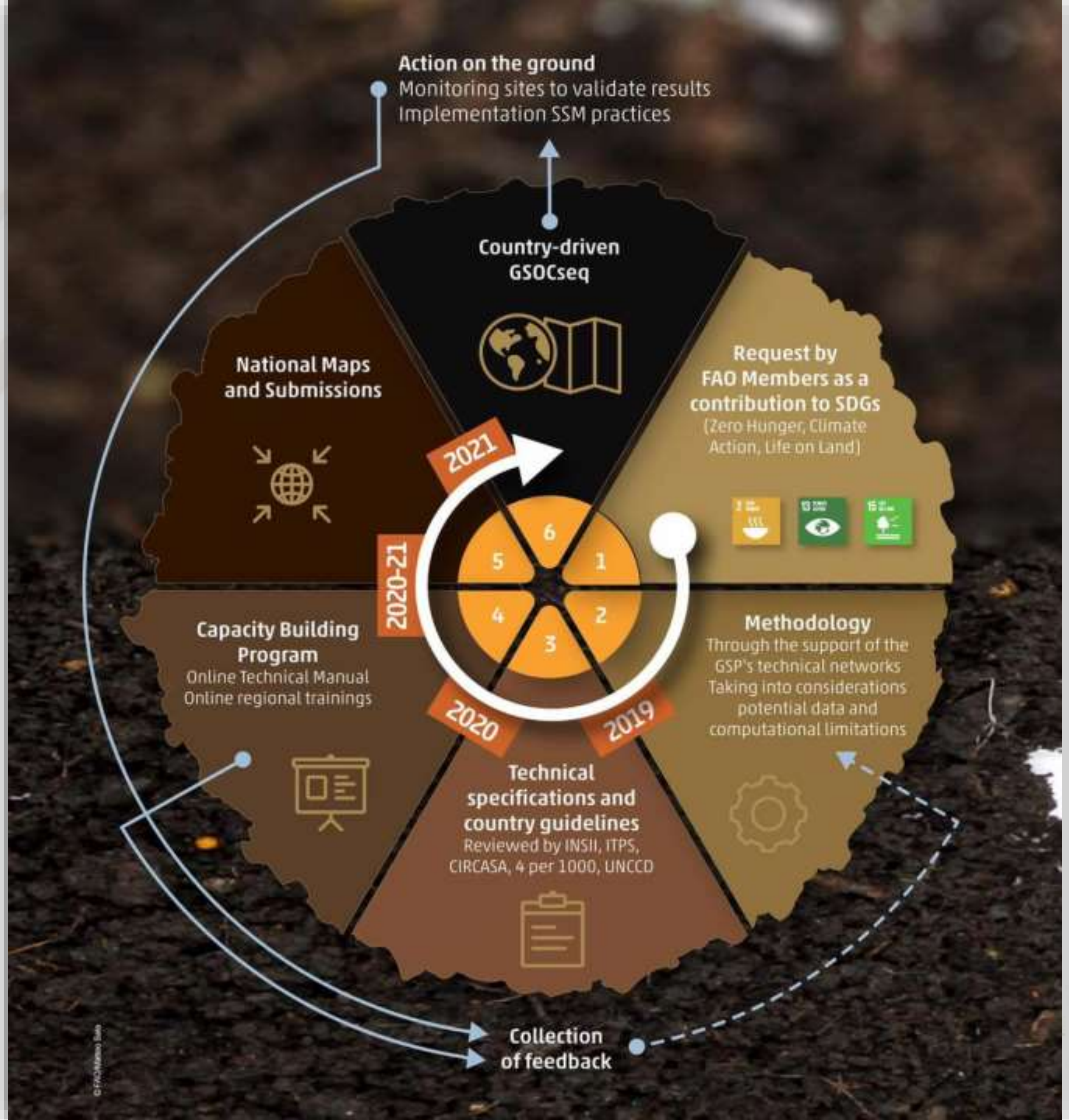
1. **Set** attainable and evidence based **national targets for carbon sequestration;**

2. **Identify areas** that have high SOC sequestration **for SSM projects**

3. **Enhance National capacities** on sustainable soil management, soil data management, digital soil mapping and modelling; as inputs for NDCs and reporting

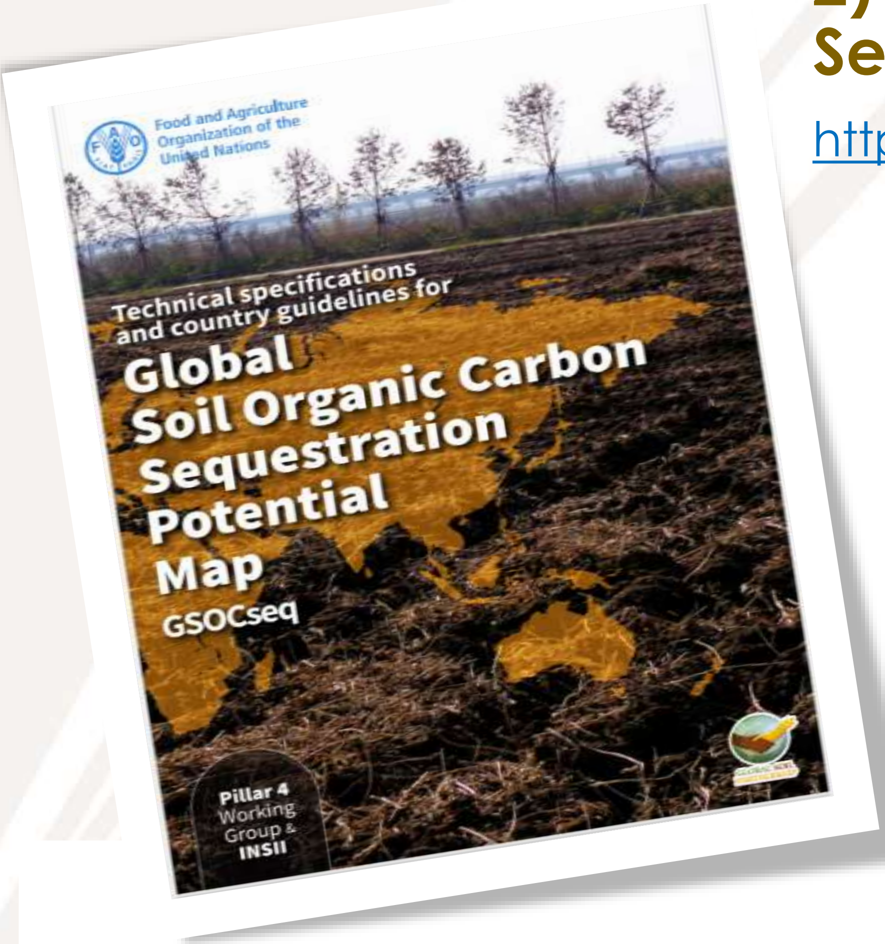
GSOCseq

A country driven process



GLOBAL SOIL PARTNERSHIP

The GSOCseq approach



1) Technical Specifications and Country guidelines

http://www.fao.org/documents/card/es/c/cb0353en/

2) Technical Manual Global Soil Organic Carbon Sequestration Potential Map GSOCseq

https://www.fao.org/documents/card/en/c/cb2642en/

Contributors and reviewers

Professor Pete Smith – University of Aberdeen

INSII - International Network of Soil Information Institutions

ITPS - Intergovernmental Technical Panel on Soils

4per1000 SCT - 4 per 1000 Scientific and Technical Committee

CIRCASA - (Coordination of International Research Cooperation on Soil Carbon Sequestration in Agriculture)

UNCCD-SPI - The UNCCD Science-Policy Interface

The Global Soil Organic Carbon Sequestration Potential Map

GSOCseq

Methodology

- Based on the **process-based model RothC**
- **3 SSM scenarios and 1 business as usual**
- Uncertainty based on the uncertainties of the input data

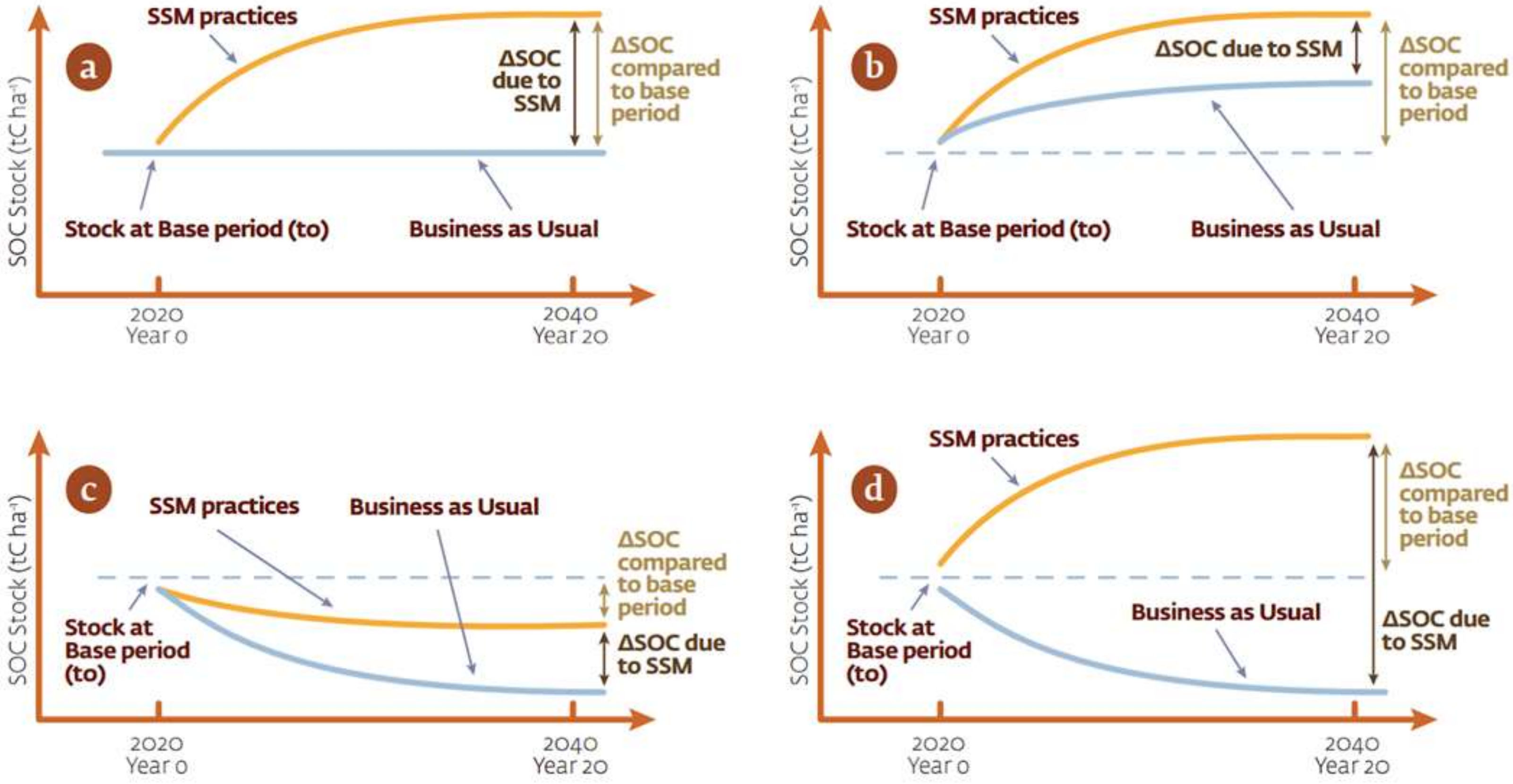
Extent

- **Agriculturally managed lands** where SSM can be implemented
- **20 years** into the furute (t0=2020, t=2020)
- **1 km resolution**

Process

- **Country-driven** (global map based on national submissions)
- Launched in 2021, continously updated following a **Versoning system**

Absolute and relative SOC sequestration

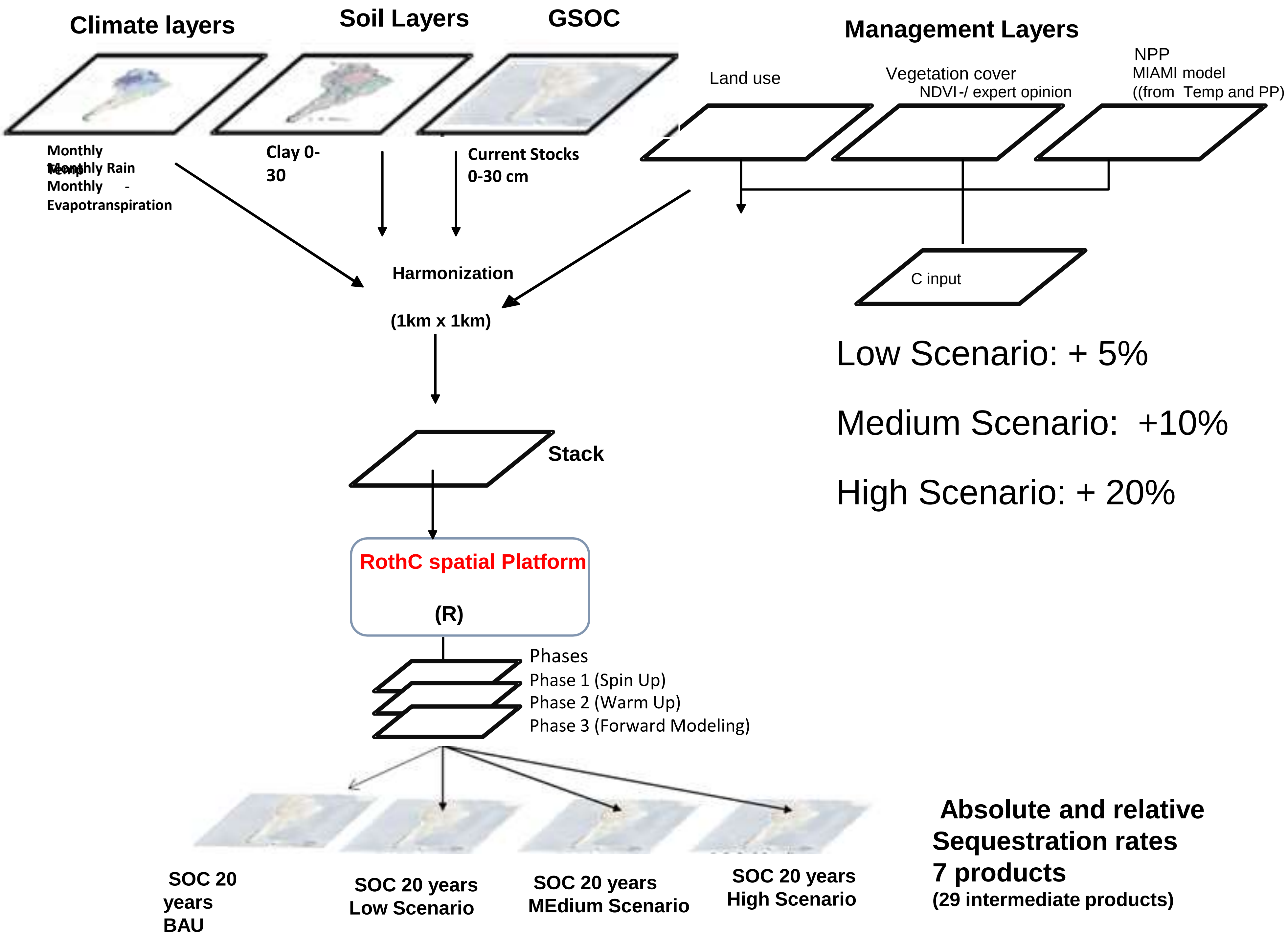


SOC sequestration (Difference) = Δ SOC in 20 years

Annual Sequestration rate = Δ SOC / 20 years

Absolute sequestration rate = (Final SOC SSM 2040– Initial SOC 2020)/ 20 years

Relative Sequestration rate= (Final SOC SSM 2040– Final SOC BAU 2040)/ 20 years



Climate layers
Soil Layers
GSOC
Management Layers
Monthly Temp
Monthly Rain
Monthly - Evapotranspiration
Clay 0-30
Current Stocks 0-30 cm
Land use
Vegetation cover
NDVI-/ expert opinion
NPP
MIAMI model
((from Temp and PP)
C input
Harmonization
(1km x 1km)
Low Scenario: + 5%
Medium Scenario: +10%
High Scenario: + 20%
Stack
RothC spatial Platform
(R)
Phases
Phase 1 (Spin Up)
Phase 2 (Warm Up)
Phase 3 (Forward Modeling)
SOC 20 years BAU
SOC 20 years Low Scenario
SOC 20 years MEdium Scenario
SOC 20 years High Scenario
Absolute and relative Sequestration rates
7 products
(29 intermediate products)

Why RothC as standard model?

- **Standard method** among countries (DayCent, Century, ICBM, YASSO,DAISY,AMG, CLM5, etc)
  - Fewer **data requirements**; data relative simple to obtain;
  - It has been applied across several ecosystems, climate conditions, soils and land use classes;
  - Successfully applied at **national, regional and global scales**; e.g. Smith et al. (2005), Smith et al. (2007), Gottschalk et al. (2012), Wiesmeier et al. (2014), Farina et al. (2017), Mondini et al. (2018), Morais et al.(2019);
  - It (or its modified/derived version) has been used to estimate carbon dioxide emissions and removals in different **national GHG inventories as a Tier 3 approach**; Smith et al. (2020): Australia (as part of the FullCam model, Japan (modified RothC), Switzerland, and UK (CARBINE, RothC).

RothC Data requirements

Climate

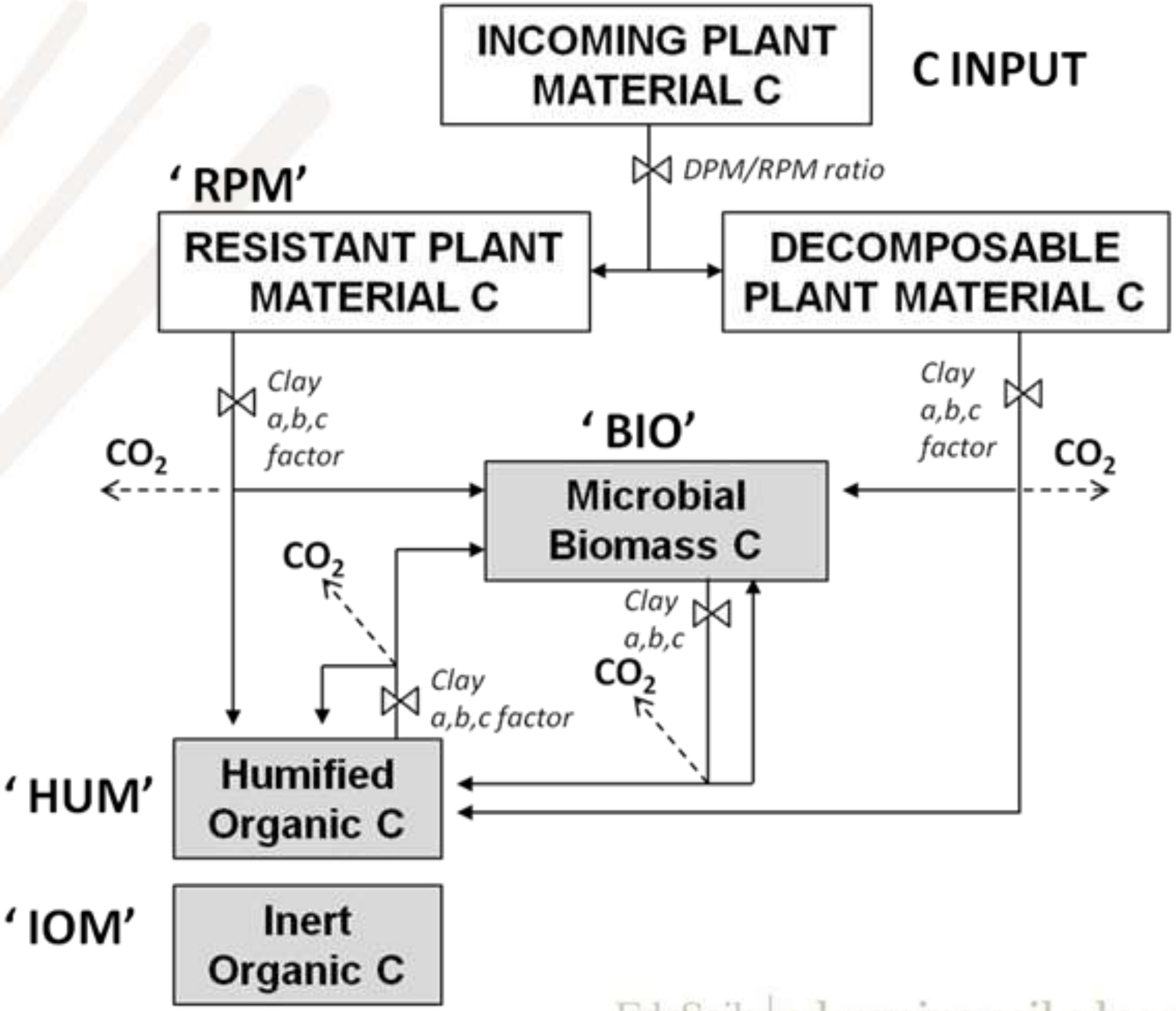
Soil

Management

Climate Data	Soil Data	Land Use- Management Data
1. Monthly rainfall(mm) 2. Average monthly mean air temperature (ºC) 3. Monthly open pan evaporation (mm)/evapotranspiration (mm) Penman-Monteith	1. Total initial 0-30cm SOC stocks (t C ha^{-1}) 2. Initial C stocks of the different pools (t C ha^{-1}): DPM, RPM, BIO, HUM, IOM 3. Clay content (%) at simulation depth.	1. Monthly Soil cover (binary: bare vs. vegetated) 2. Irrigation (to be added to rainfall amounts) 3. Monthly Carbon inputs from plant residues (aboveground + belowground), (t C ha^{-1}) 4. Monthly Carbon inputs from organic fertilizers and grazing animals' excretion (t C ha^{-1}) 5. DPM/RPM ratio, an estimate of the decomposability of the incoming plant material

2. Country driven Approach

RothC



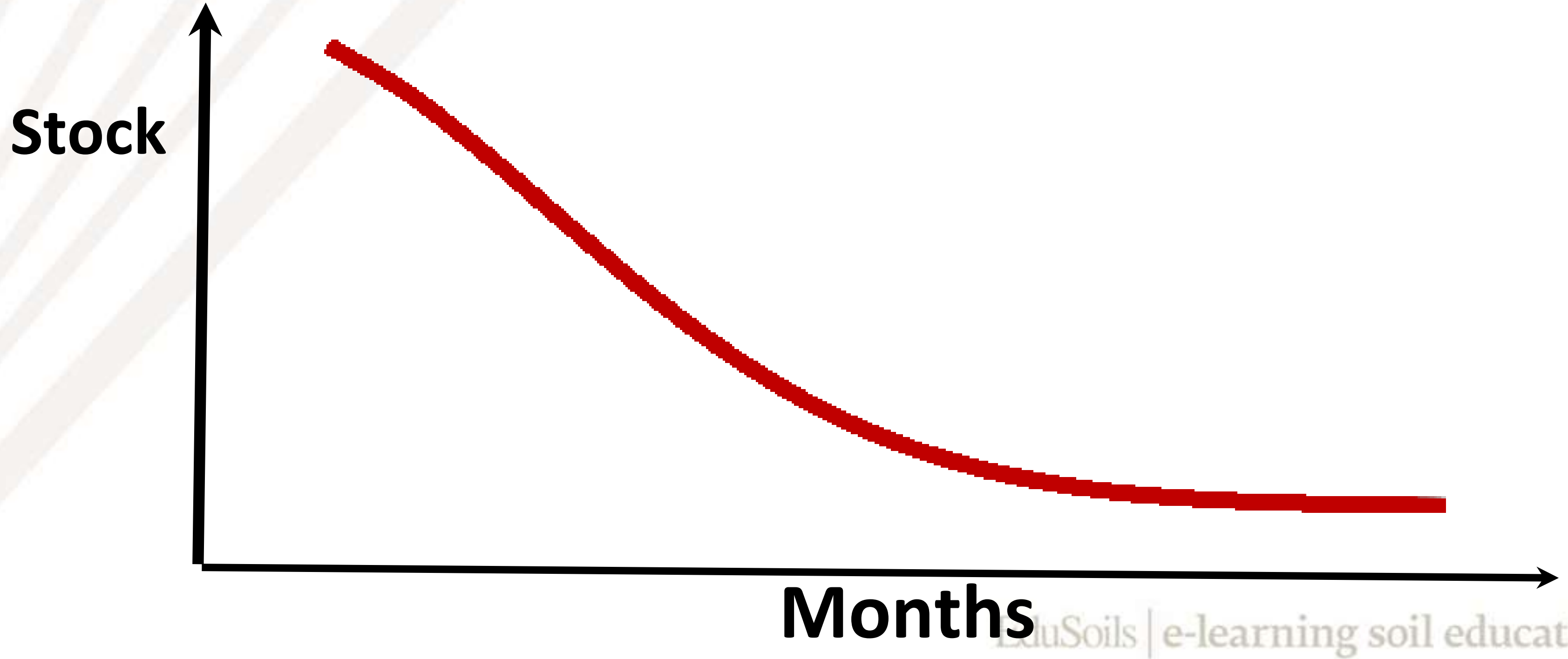
SOC dynamics in RothC

The amount of SOC of each pool (Y) decomposes following an **exponential decay function**:

$$Y \cdot e^{-kt}$$

k = annual decomposition constant

t = time, months 1/12 (0,083)



Decomposition rates

Constants (*k*), *in years^{-1}, different for each pool:*

- DPM (decomposable plant mat): **10.0** .... 0.1 years (turnover time)
- RPM (resistant plant material): **0.3** ......3.3 years
- BIO (microbial biomass): **0.66** .... 1.5 years
- HUM (Humified organic C) : **0.02** .... 50 years
- IOM (Inert) .....0.000000 .... ɑ

SOC dynamics in RothC

... These **k** are affected by different factors:

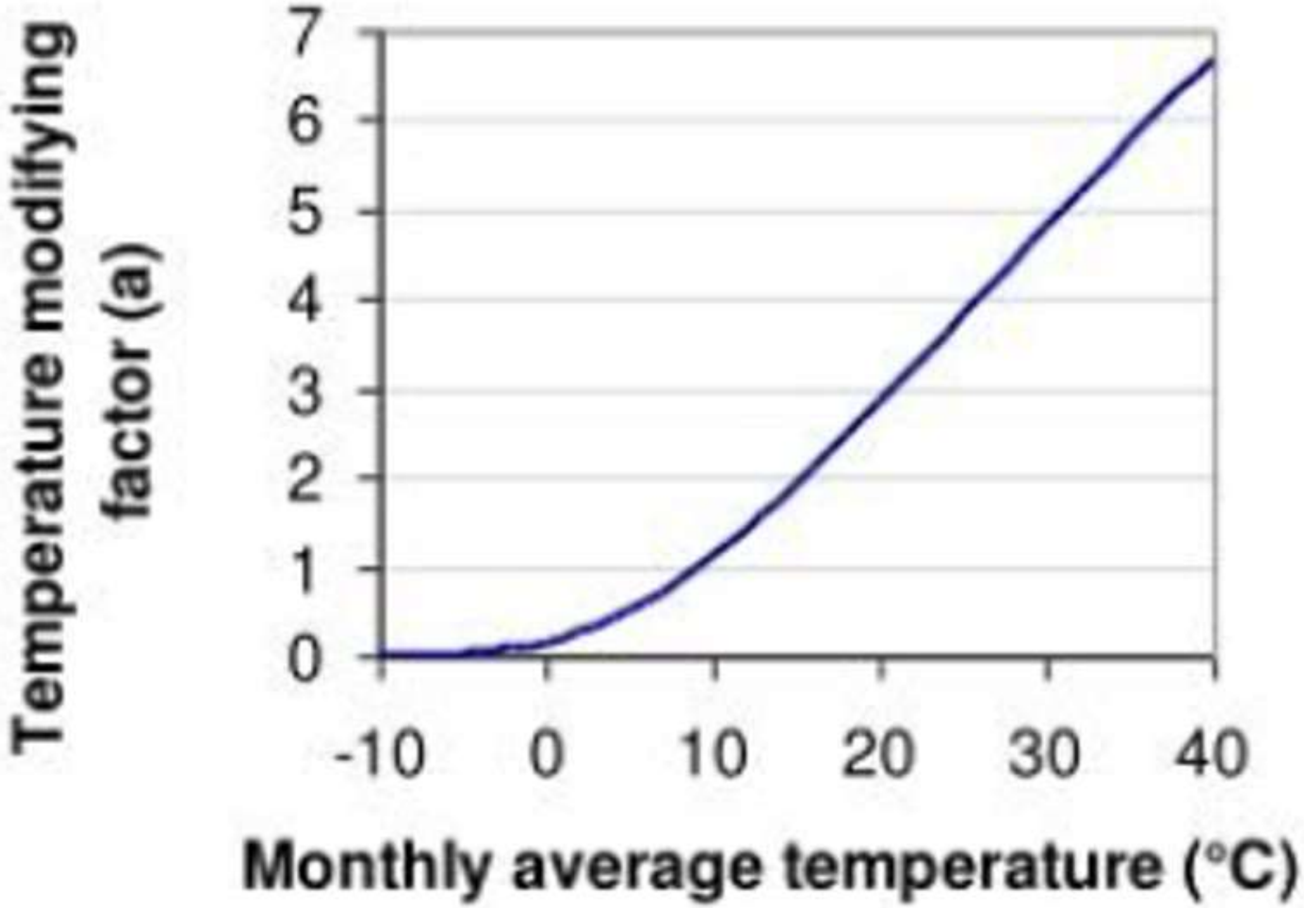
$$Y \,.\, e^{-kt} \Rightarrow Y \,.\, e^{-k.\,a.b.c.\,t}$$

a= temperature factor

b= soil moisture factor

c= soil cover factor

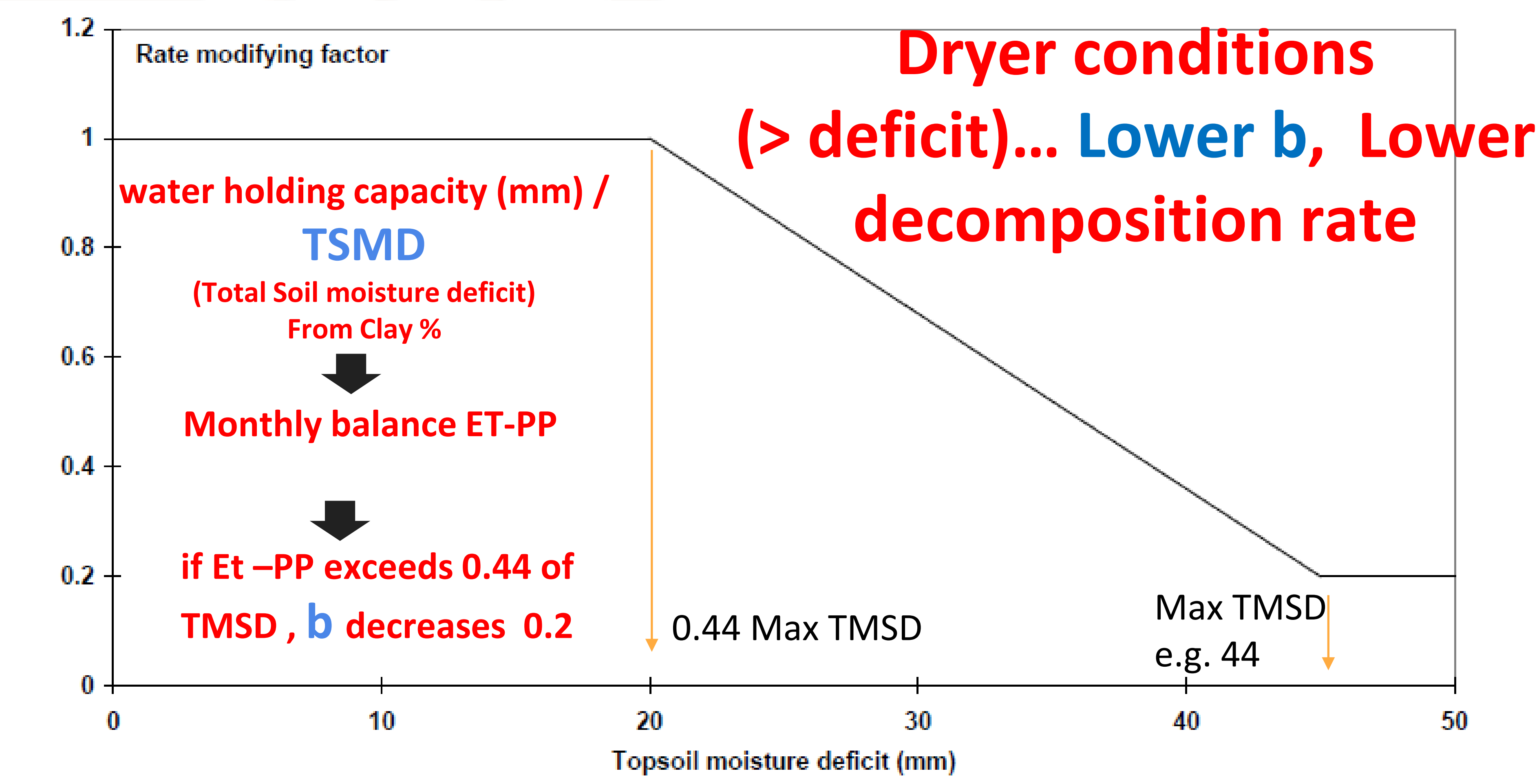
Temperature factor (a)



> Temperature,
> decomposition rate

From: CSIRO: 2008

Soil moisture factor (b)



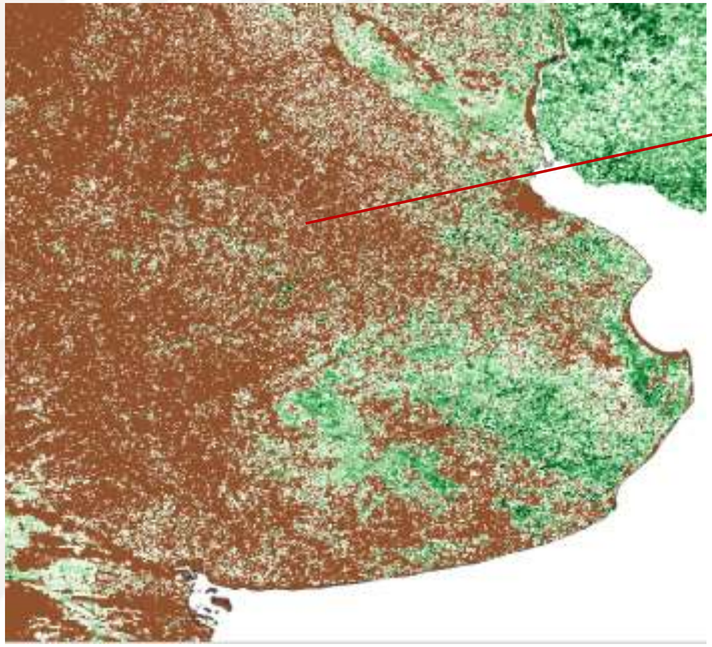
platform GLOBAL SOIL PARTNERSHIP

Soil/vegetation cover factor (c)

If soil is vegetated c=0.6

If soil is bare c=1.0

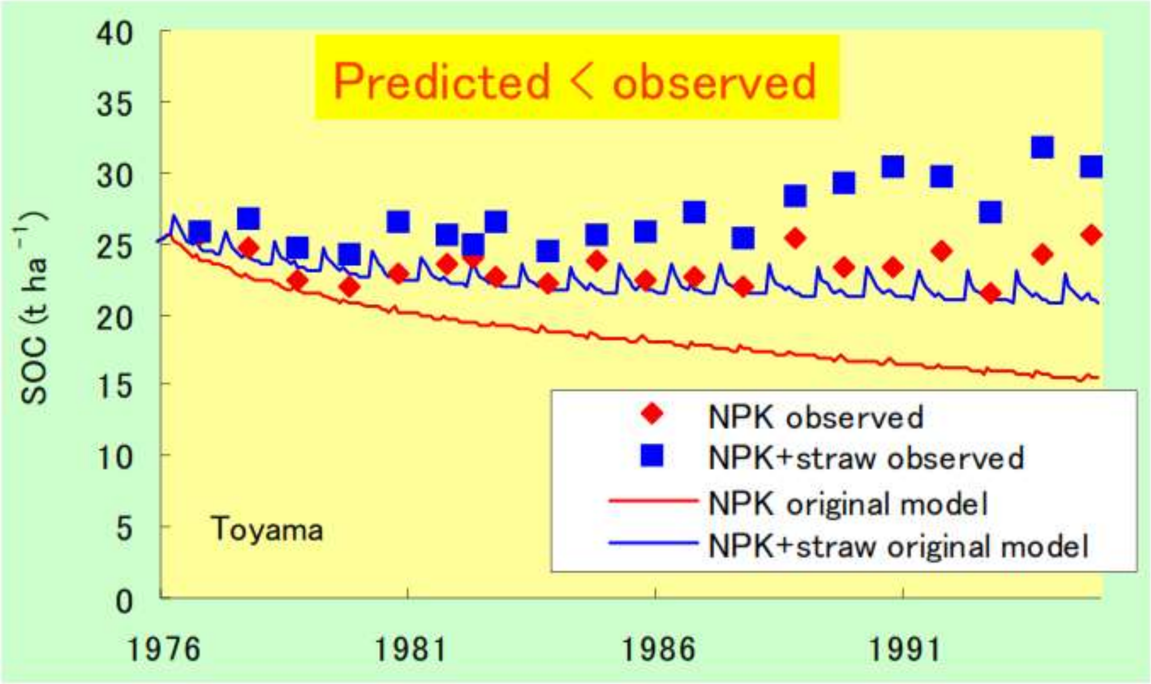
If Vegetated, Lower "c" Lower decomposition rate



July
No crops
Bare;
c=1.0

January
Growing
crops
veg.;
c=0.6

Example RothC Japan – Paddy Rice - watterlogged soils



The model underestimated SOC, as expected
(slower decomposition because of anaerobic condition)

From:Yirato y Yagasaki. NIAES

(Shirato & Yokozawa, 2005)

Modifying factor for paddy rice

0.6 x k months no flooded rice

0.2 x k with flooded Rice

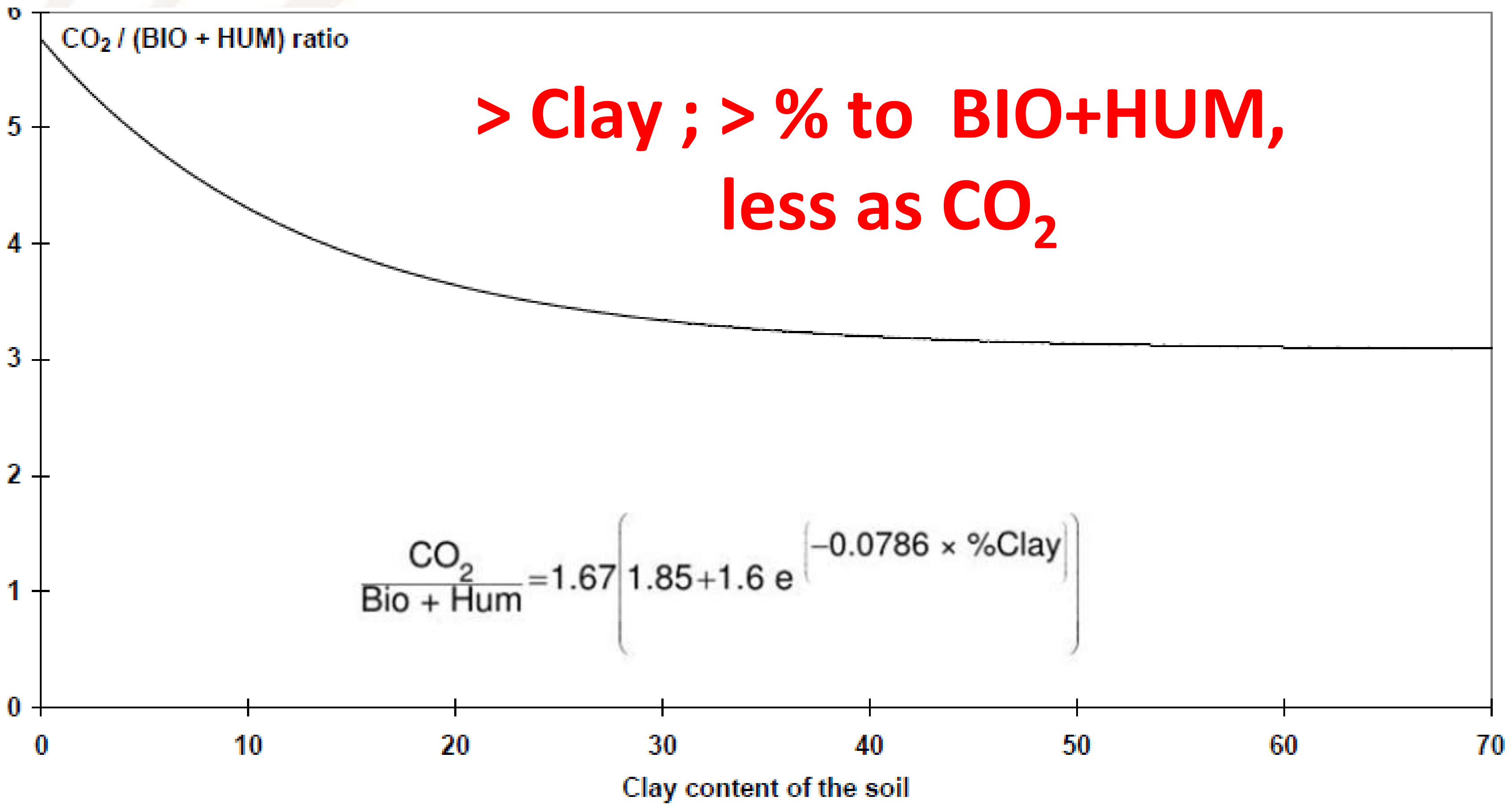
Paddy rice modifying factor GSOCseq= 0.4 x k

Soil texture

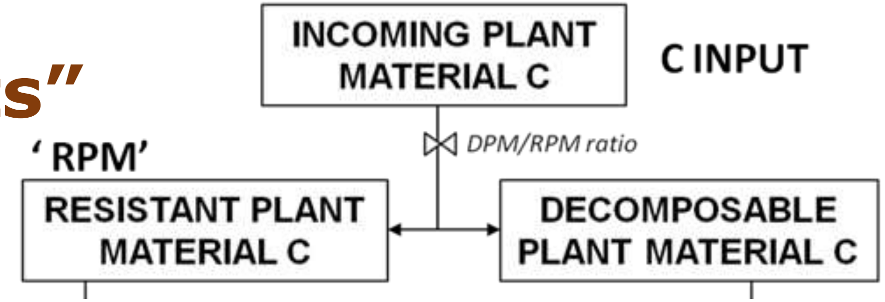
Clay%

… affects the proportion of C from each pool that is released as **CO_2** or to **Soil organic carbon pools**

- From that… **46 % goes to BIO**; **54% goes to HUM**



DPM/RPM… "Decomposability of C inputs"
C inputs split between DPM and RPM



Default values…

- Crops and improved pastures…

DPM/RPM = 1.44 (59% is DPM, 41% is RPM)

- Grasslands, shrublands/savannas

DPM/RPM = 0.67 (41% is DPM; 59% is RPM)

Tree crops

variable…DPM/RPM = 1.44; 0.67; 0.35

(Morais et al 2019;Farina et al 2017)

- Forests (deciduous, tropical)…

DPM/RPM =0.25 (20% is DPM y 80% is RPM)

- Manure…

DPM/RPM =1 (49% is DPM; 49% is RPM ; 2%HUM)

- Depends on Land Use
- Can be modified

RothC – Soil R

Sierra et al., 2012; 2014

Geosci. Model Dev., 5, 1045–1060, 2012
www.geosci-model-dev.net/5/1045/2012/
doi:10.5194/gmd-5-1045-2012

Geoscientific Model Development

Models of soil organic matter decomposition: the SoilR package, version 1.0

C. A. Sierra, M. Müller, and S. E. Trumbore
Max Planck Institute for Biogeochemistry, Hans-Knöll-Str. 10, 07745 Jena, Germany
Correspondence to: C. A. Sierra (csierra@bgc-jena.mpg.de)

Received: 29 March 2012 – Published in Geosci. Model Dev. Discuss.: 2 May 2012
Revised: 2 August 2012 – Accepted: 4 August 2012 – Published: 24 August 2012

https://www.geosci-model-dev.net/5/1045/2012/gmd-5-1045-2012.pdf

Soil R site:

https://www.bgc-jena.mpg.de/TEE/software/soilr/

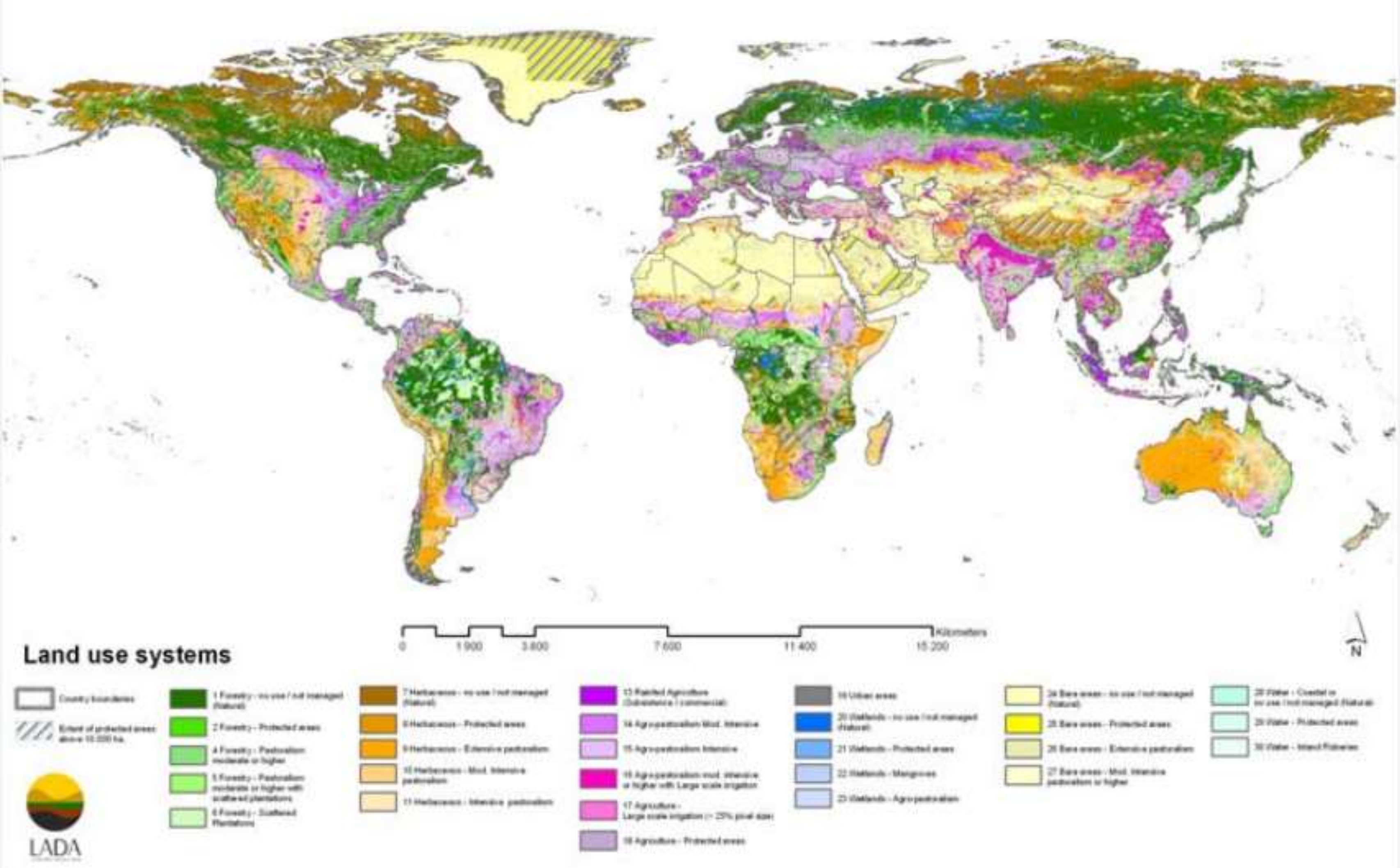
- SoilR- simplified version of RothC – Higher speed, adapted to simulate multiple objects (e.g. 1 km x 1 km)
- Transparent, R language, can be modified
- Open Software (R)
- SoilR, already integrates othes SOC models (e.g. ICBM, Century)…to perform model ensemble approach

Spatial Version RothC Soil-R

- GSP: We provide a tool based in R language using Soil R – RothC functions
- Each country can improve and modify the tool, develop their own tool (using Roth C to generate the standard products in a first stage)
- **Countries are encouraged to provide additional (´non-standard´) sequestration maps, using modifications/adaptations, alternative approaches, other models**

How to harmonize and model thousands of different practices, often combined? …Specially with limited data

SSM? Land use systems of the world



… First stage…

Practices that increase C inputs

3 scenarios:

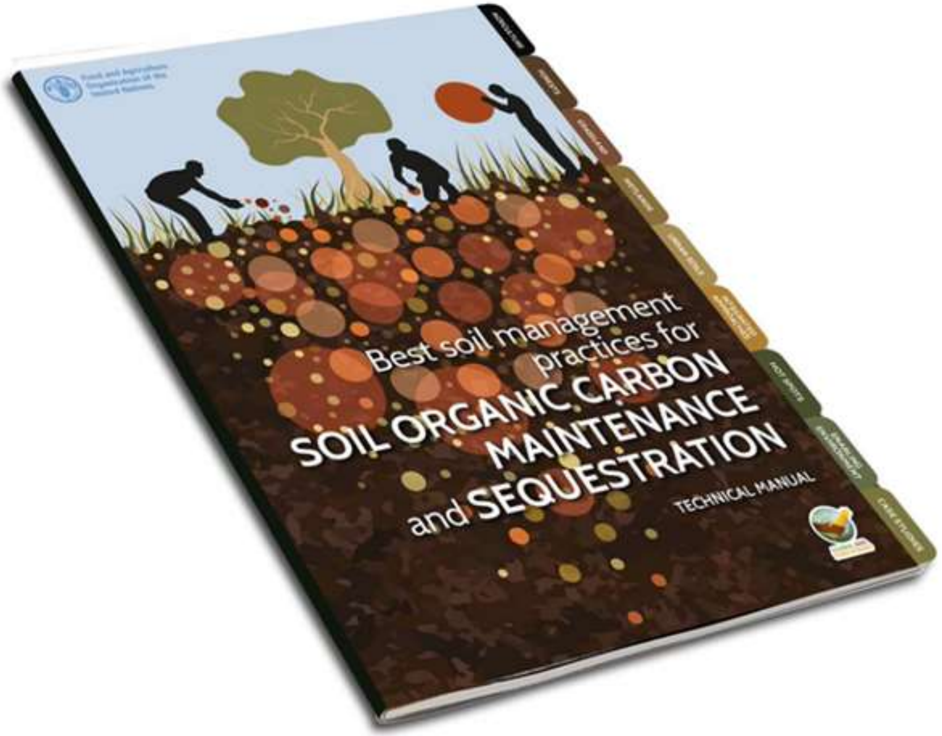
- **+5% increase Ci**
- **+10% increase Ci**
- **+20% increase Ci**

Conservative ranges…may be high for other systems

based on Smith, 2004; Wiesmeier et al., 2016

SSM practices

"Technical manual of recommended management practices for SOC maintenance and Sequestration"

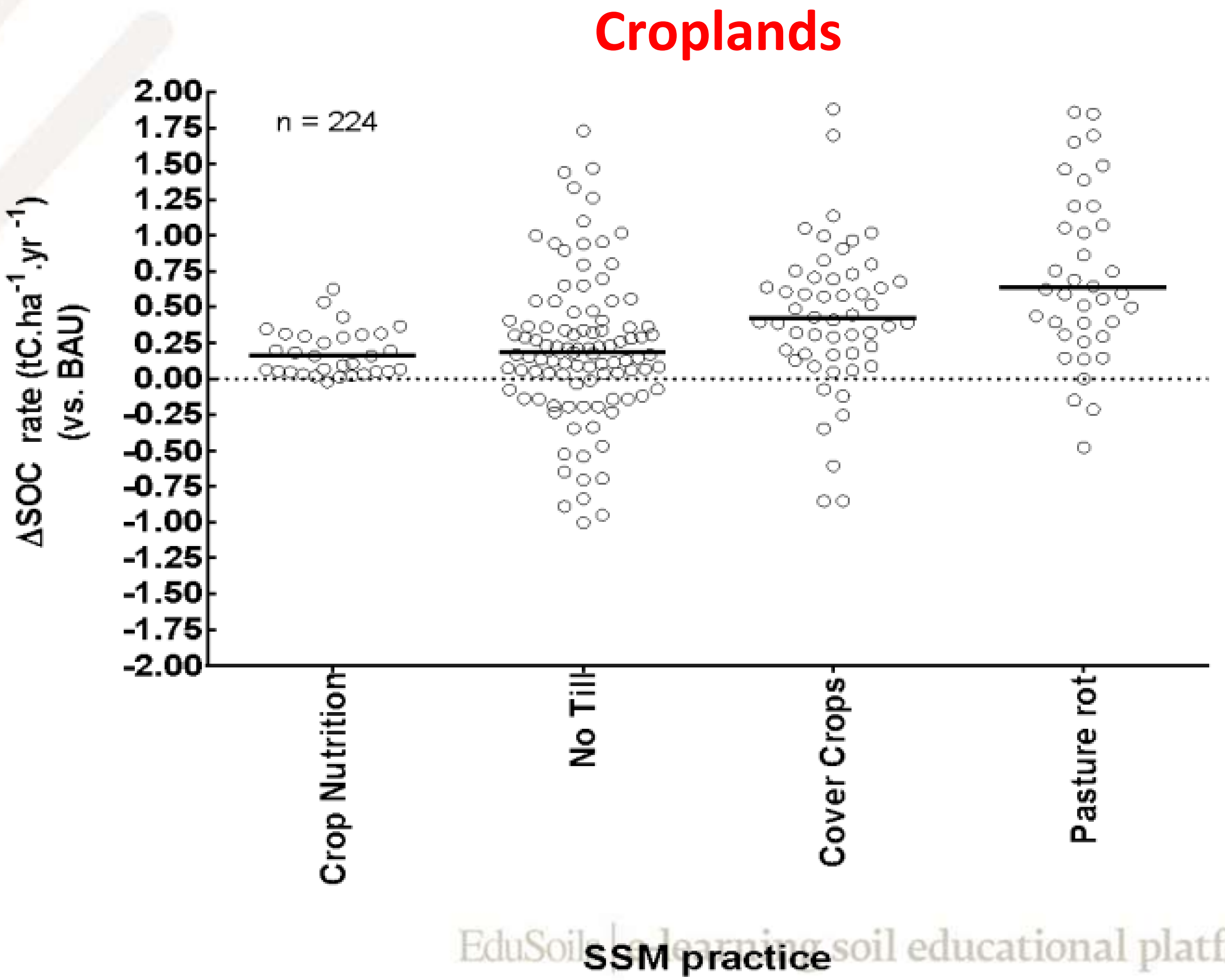


..and many other practices around the world…

Local adjustment of scenarios and % increase in C inputs

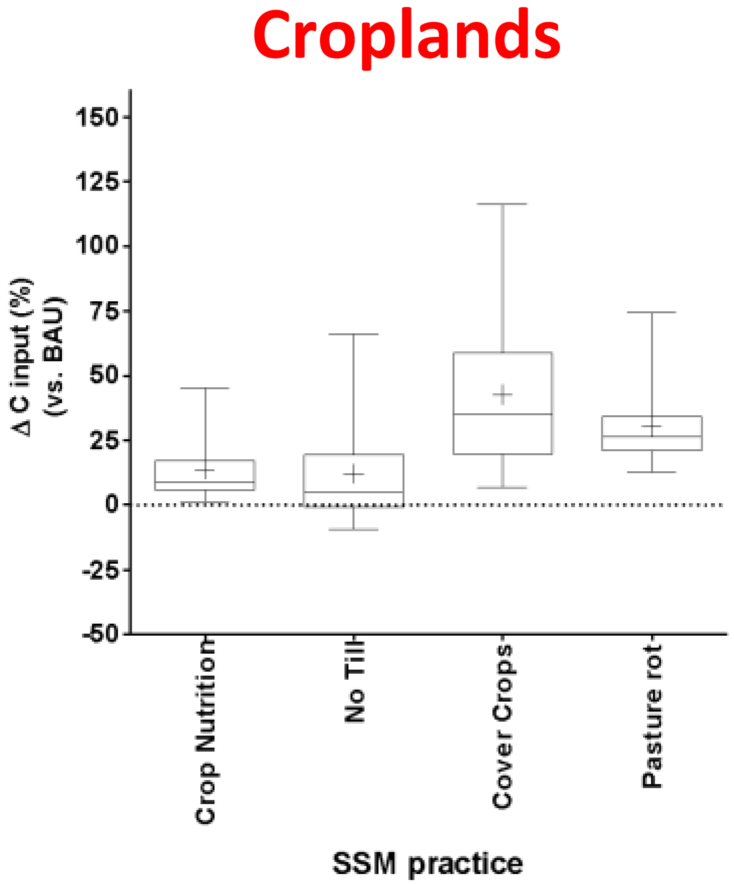
E.g.

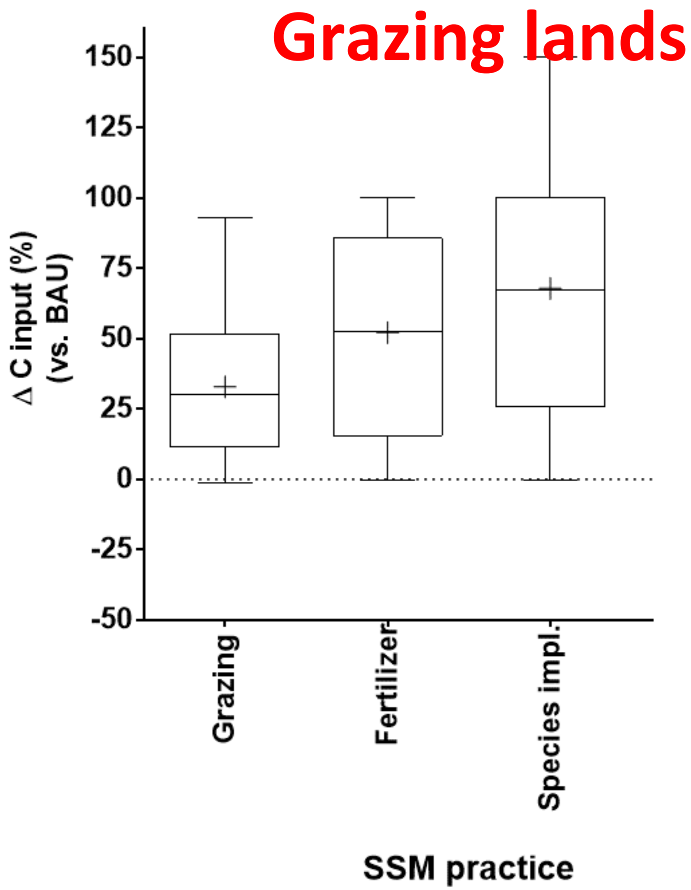
Ad hoc Meta-analysis from local studies



Local adjustment of scenarios and % increase in C inputs

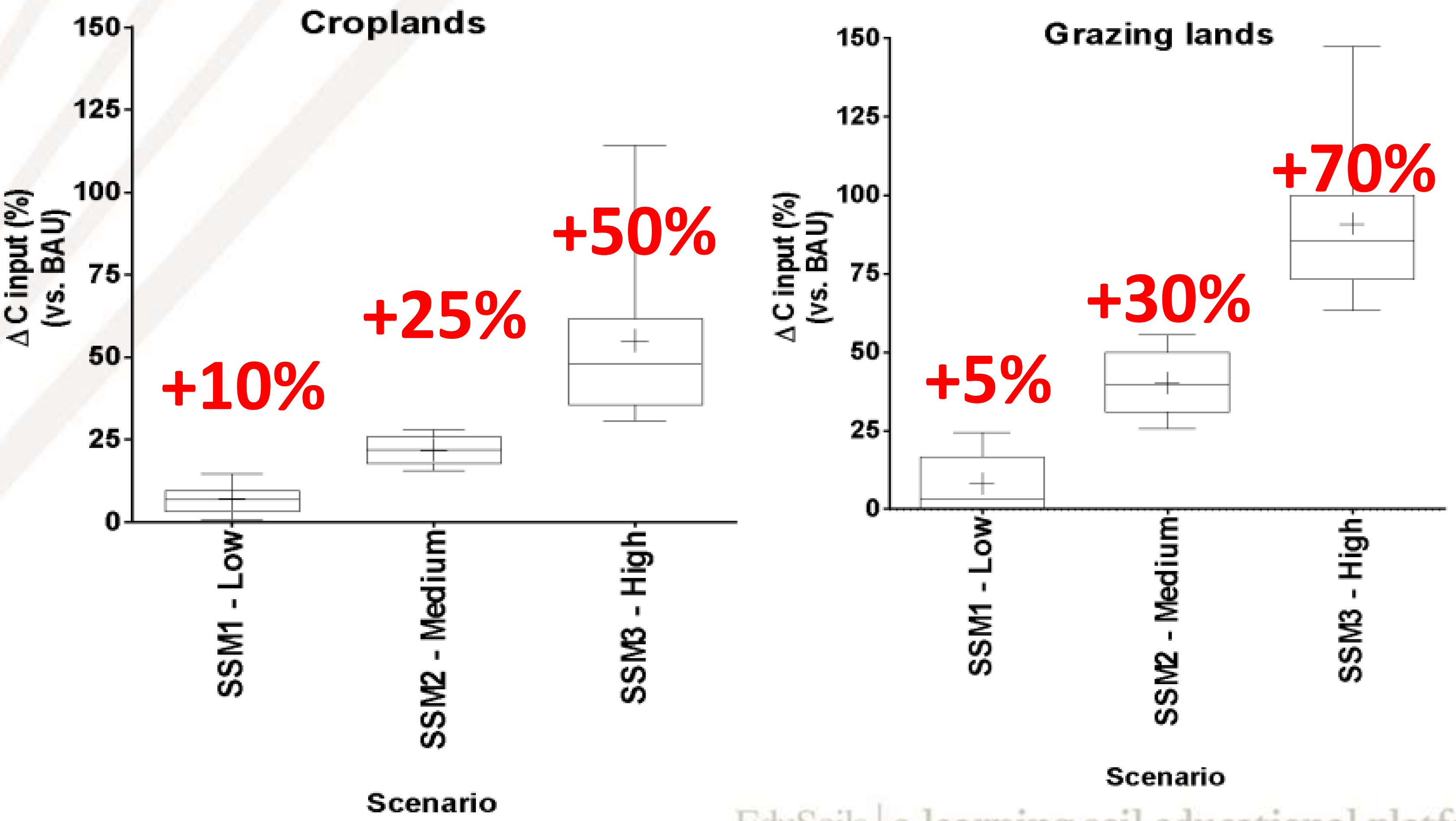
E.g. Ad hoc Meta-analysis from local studies



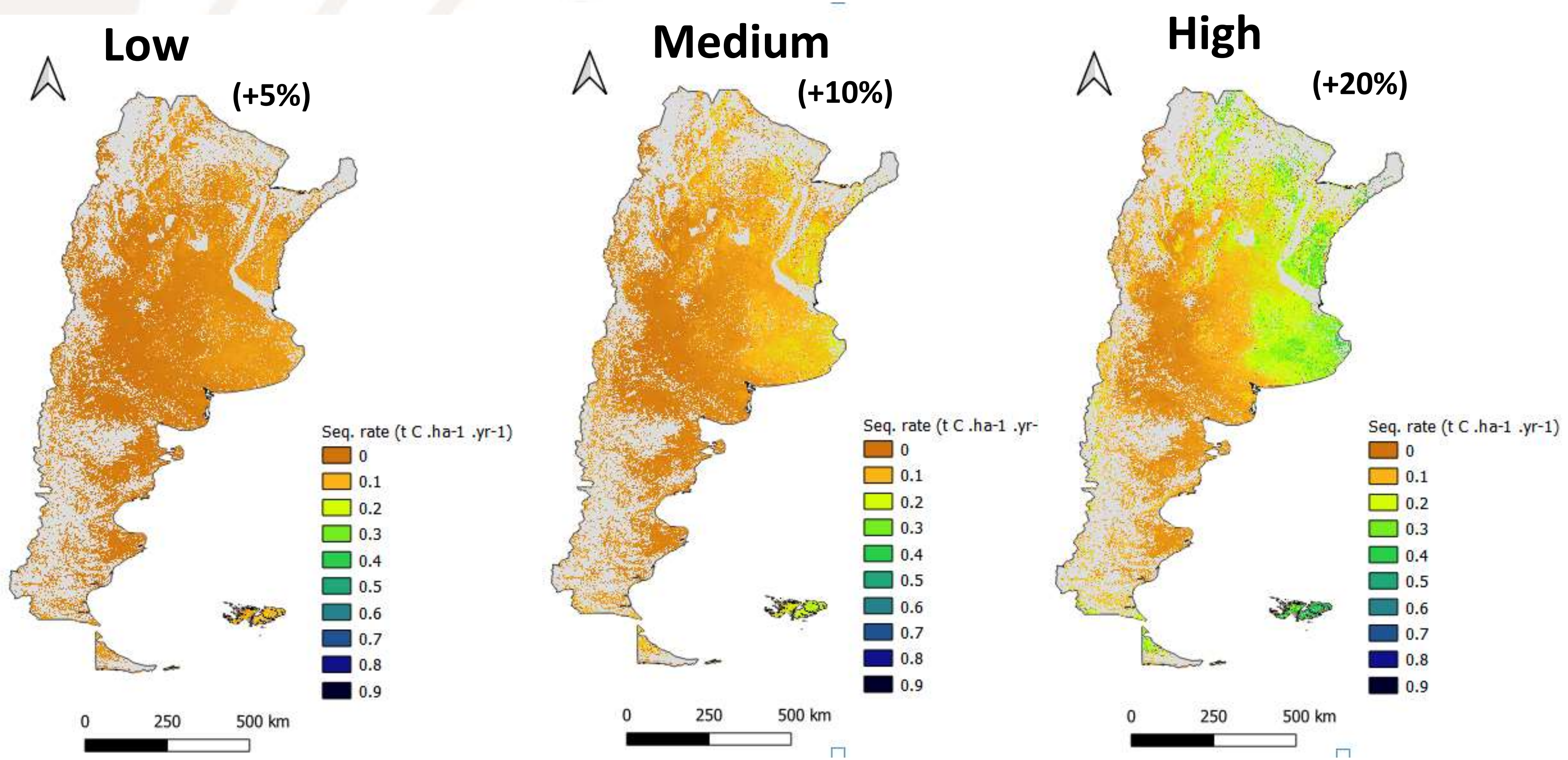


Local adjustment of scenarios and % increase in C inputs

E.g.



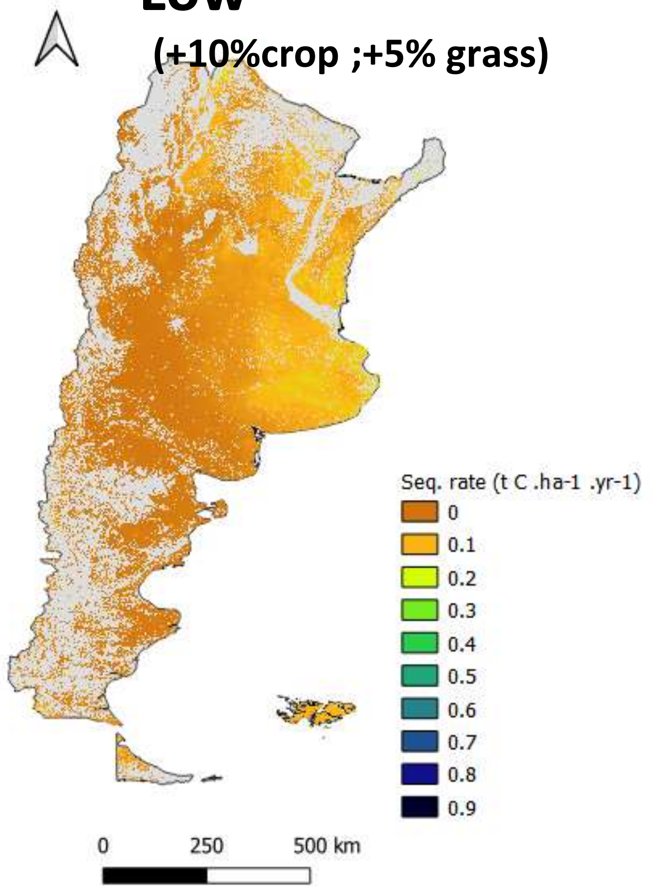
Standard Products



Non-Standard Products
Using modified coefficients

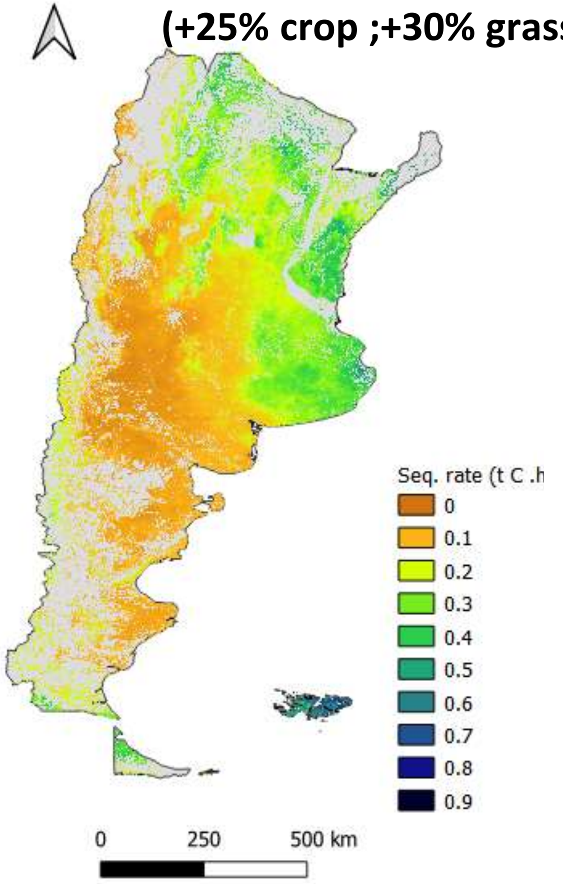
Low

(+10%crop ;+5% grass)



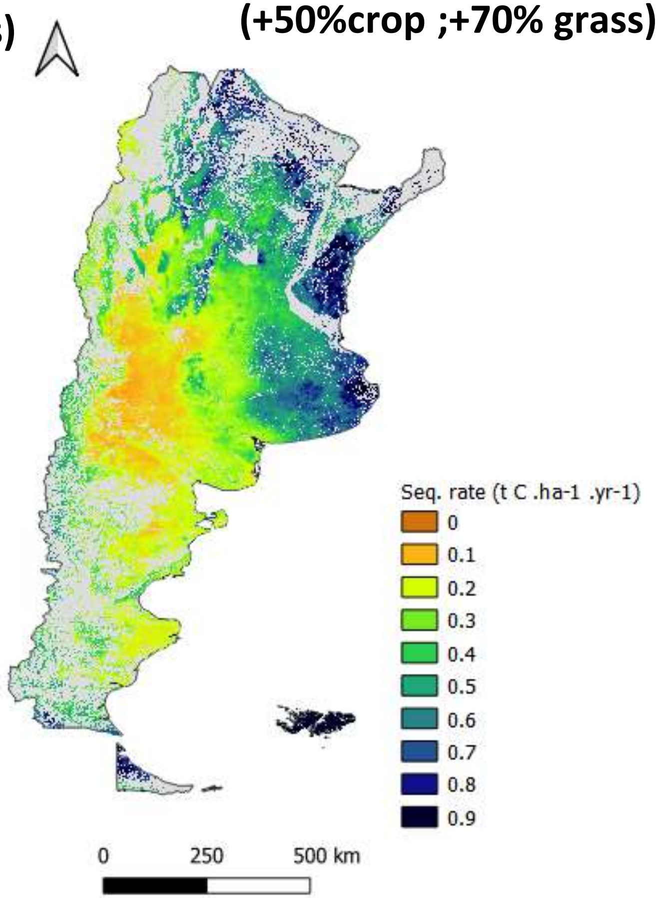
Medium

(+25% crop ;+30% grass)

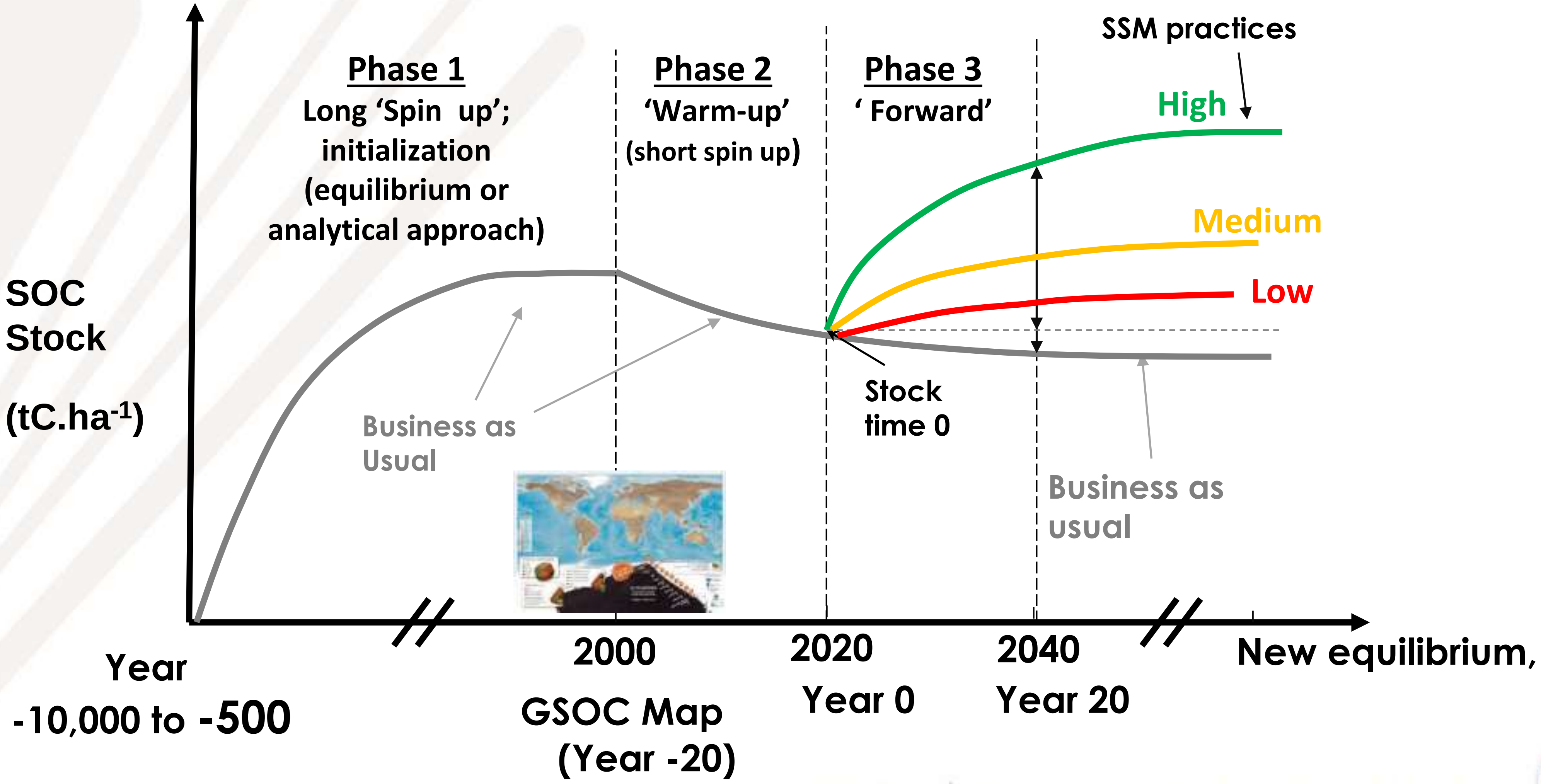


High

(+50%crop ;+70% grass)

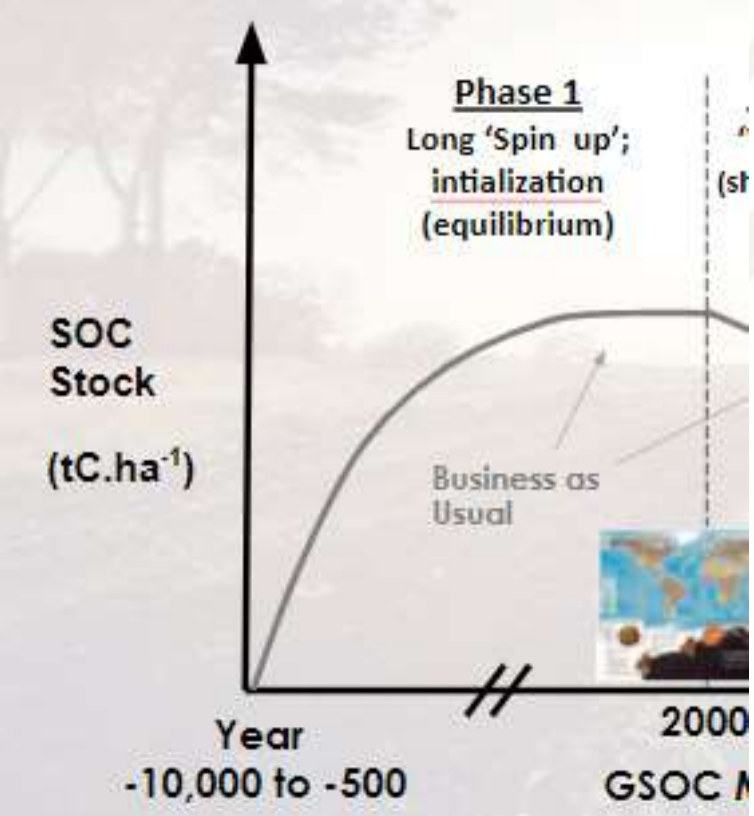


For each 1km x 1km pixel:



Approach based on Smith et al 2006; 2008; Gottschalk et al. 2012

Phase 1 . Spin up



Initialization phase

Required to:

- **obtain C stocks of different pools (BIO, HUM, DPM, RPM, etc)**
- **Estimate baseline C-inputs (C inputs required to reach GSOC stocks) (referred as Ceq)**

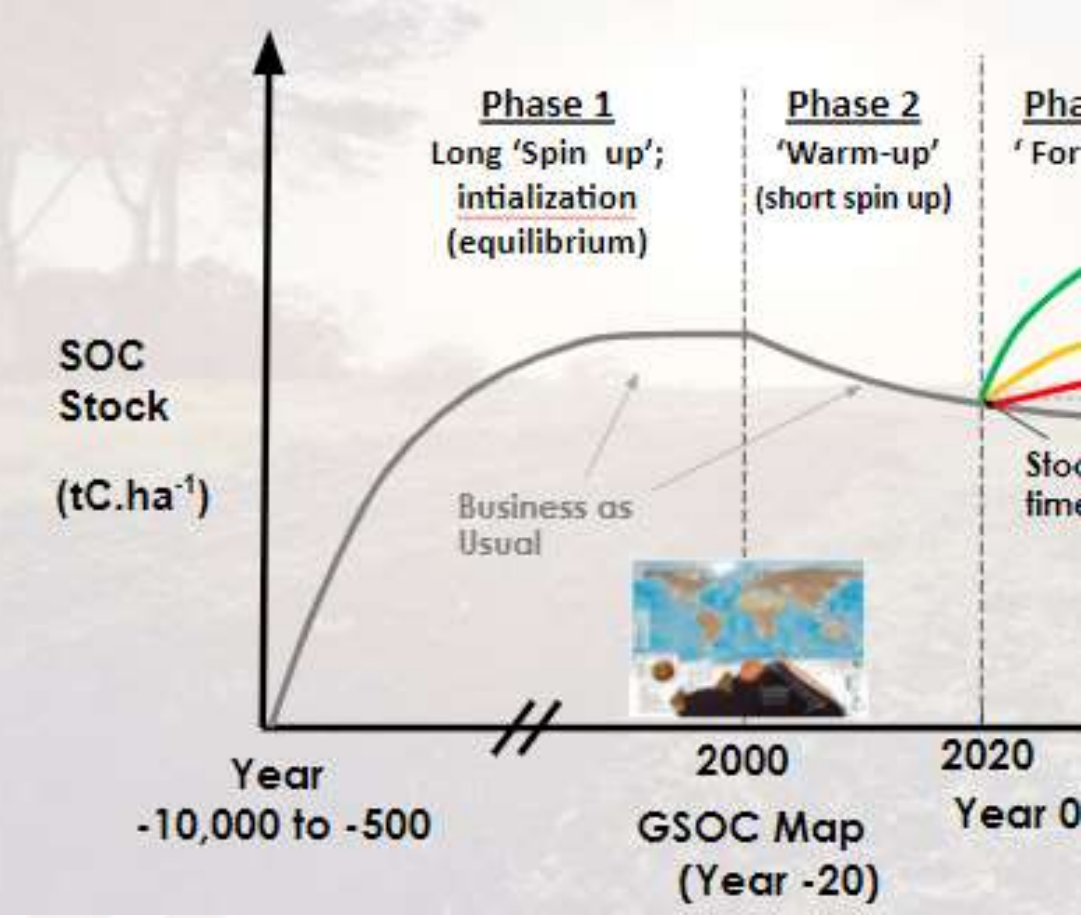
Ceq = C inputs under business as usual/baseline

Procedure:

Model is run for a long time span (e.g. 500 years) using historic climate (1980-2000)… first using a fixed C input (1 t)… C inputs are adjusted until SOC stock = GSOC map:

- $C_{eq}=C_i\times[(C_{meas}-IOM)/(C_{sim}-IOM)]$

Phase 2 . Warm up – Short Spin up (18-20 years)



Required to:

- Adjust climate variation between 2000-2020
- Harmonize major time differences in GSOC map FAO (generated soil profiles 1960-2000s)... current
- Adjust Land use changes 2000-2020
- Adjust over or under estimation in C stocks of a specific pool (E.g. High DPM)
- Not necessary if current SOC stocks = GSOC

Procedure:

- The model is run for 18-20 years using monthly climate data, year to year (2001-2020)
- Annual C inputs are corrected according to annual changes in NPP

Phase 2 . Warm up – Short Spin up (Cont.)

- Annual NPP to adjust year to year C inputs
- NPP by MIAMI Model (Lieth, 1972; Gottschalk et al., 2012)
- <u>Other preferred NPP sources/models can be used</u>

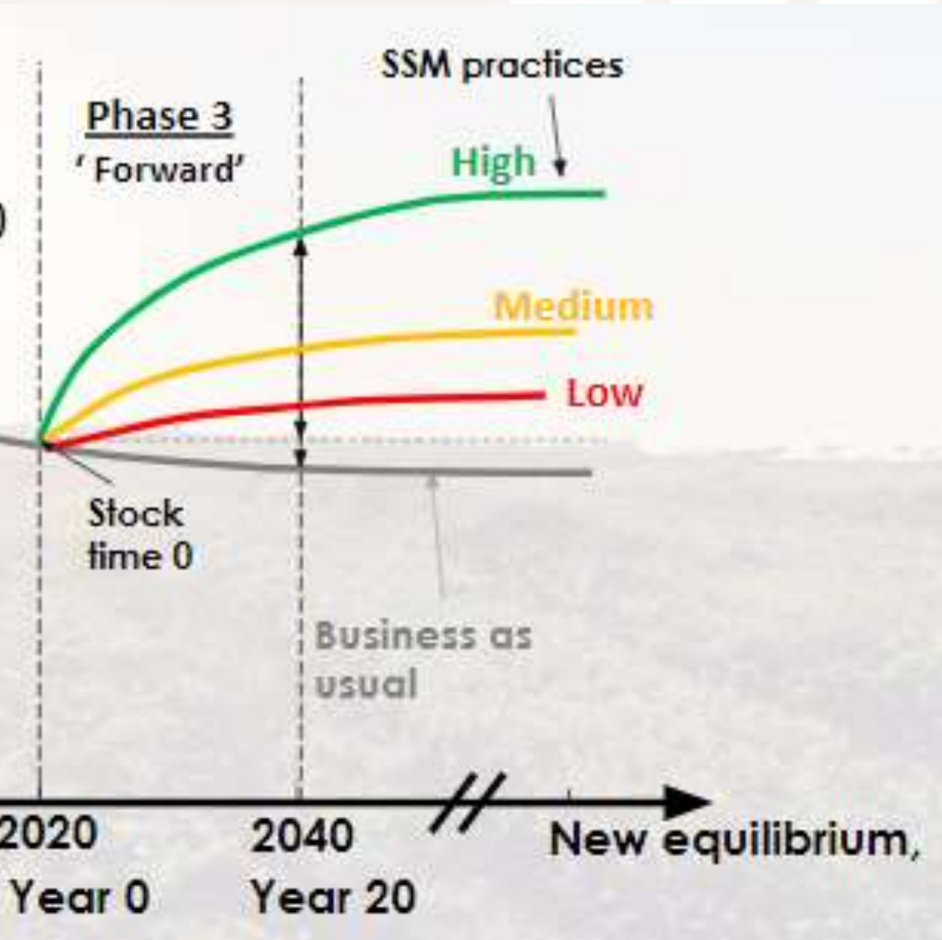
NPP can be adjusted for Land Use changes (Schulze et al 2010)

$NPPt_{forests} = NPP_{MIAMI} \times 0.88$

$NPPt_{grasslands} = NPP_{MIAMI} \times 0.72$

$NPPt_{croplands} = NPP_{MIAMI} \times 0.53$

Phase 3 . Forward run (2020 – 2040)



Required to:

- Obtain SOC stocks in different SSM scenarios after 20 years
- Estimate SOC sequestration rates

Procedure:

- Model is run for 20 years using average climate 2000-2020
- (Future versions include climate change… decide scenarios)
- **The 4 scenarios are run:**
  - **BAU**
  - **SSM1 ('Low increase') (+ 5% in C)**
  - **SSM 2 ('Medium increase') : (+10%)**
  - **SSM 3 ('High increase'): (+20%)**

Validation and uncertainties

Difficulties

- Validate changes that did not happen yet?
- Complex methods (e.g. Montecarlo) require multiple simulations (computational time)
- Data availability, uncertainty in input layers

- **We require to estimate uncertainties with limited computational and data resources**

General Uncertainties

$$U (\%) = 100 * (UL\ CI - LL\ CI) / (2 * SOCav)$$

UL = upper limit of the 95% confidence interval of the estimated SOC at the end of the simulation (in t $C.ha^{-1}$),
LL= lower limit of the 95% confidence interval of the estimated SOC at the end of the simulation (in t $C.ha^{-1}$); a

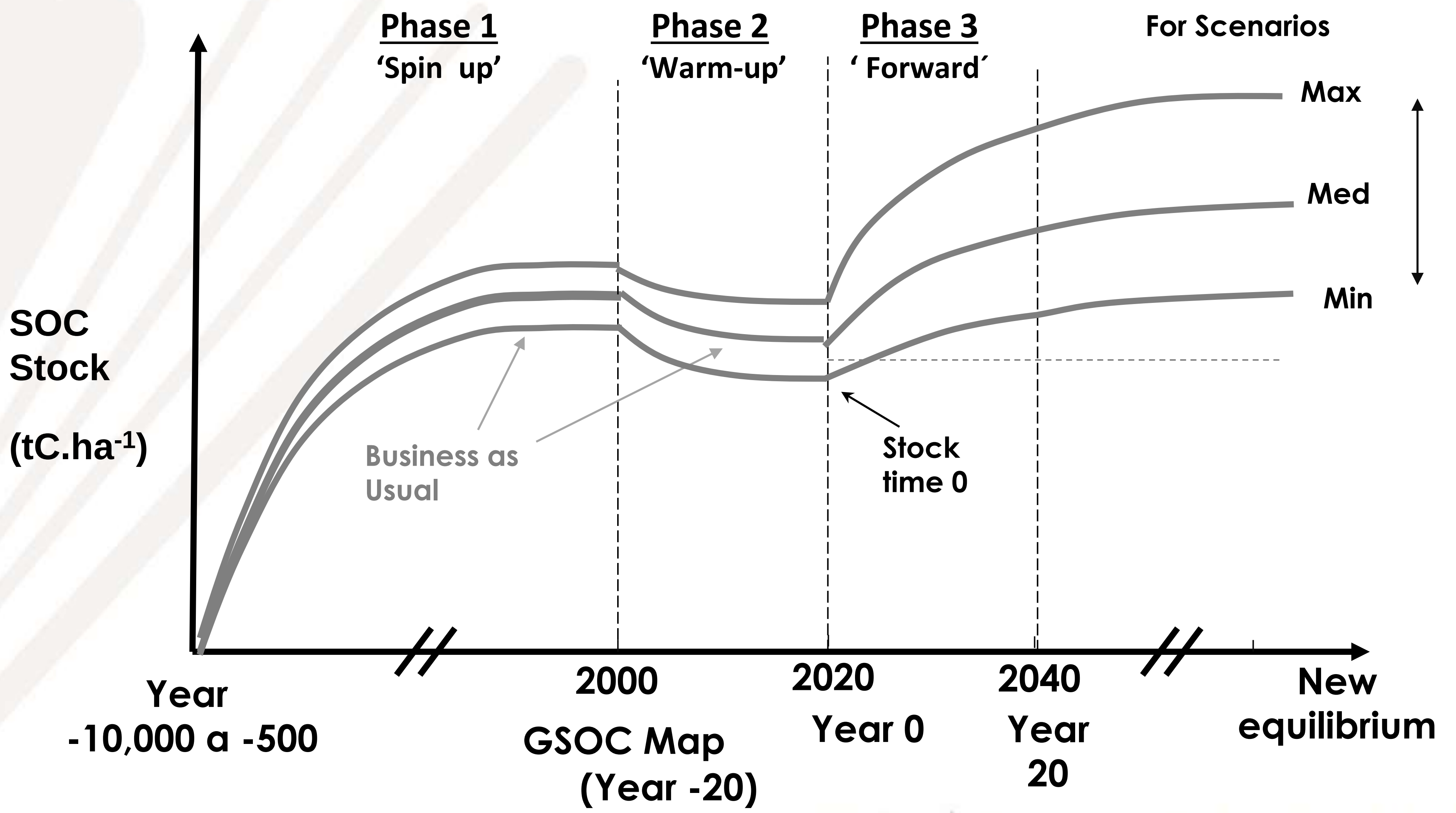
SOCav = the average of the estimated SOC at the end of the simulation (t $C.ha^{-1}$)

VCS 2012

SOC max/UL = Model (SOC FAO max, Ci max, Temp min, Pp max, Clay max)

SOC min/LL = Model (SOC FAO min, Ci min, Temp max, Pp min, Clay min)

General Uncertainties



Uncertainties

If information on uncertainty of layer for each pixel 1 km x 1km (SOC FAO, PP, Clay, Temp, etc):

P min = Xp – 1.96 x SEp

P max = Xp +1.96 x SEp

And run model changing Input Layers (using Pmin, y PmAx)

If NO information on the uncertainties of each layer , use general variation (> % uncertainties…)

General uncertainties of main parameters affecting SOC dynamics. Derived from Gottschalk et al. (2007) and Hastings et al. (2010).

Parameter	**Uncertainty in the input**	Minimum value	Maximum value
Temperature	**± 2 %**	Monthly Temp * 0.98	Monthly Temp * 1.02
Precipitation	**± 5 %**	Monthly PP * 0.95	Monthly PP * 1.05
Clay content	**± 10 %**	Clay * 0.90	Clay * 1.10
FAO SOC	**± 20 %**	SOC FAO *0.8	SOC FAO * 1.2
C input increase in SSM scenario	**± 15 %**	C eq * (SSM1 % increase - 15%)	C eq * (SSM % increase + 15%)

Limitations

- Models= simplifications of reality
- No universal models
- Erosion, Clay type? soil nutrients effects?
- pH? Bases?
- aridic soils? Sodic soils? Salt affected?
- red-ox potential; waterlogging, anaerobiosis; organic soils?
- micro and meso fauna effects?
- Soil structure ? Soil compaction?
- Among others!!!!

… But we need an initial step…

GSOCseq

http://54.229.242.119/GloSIS/

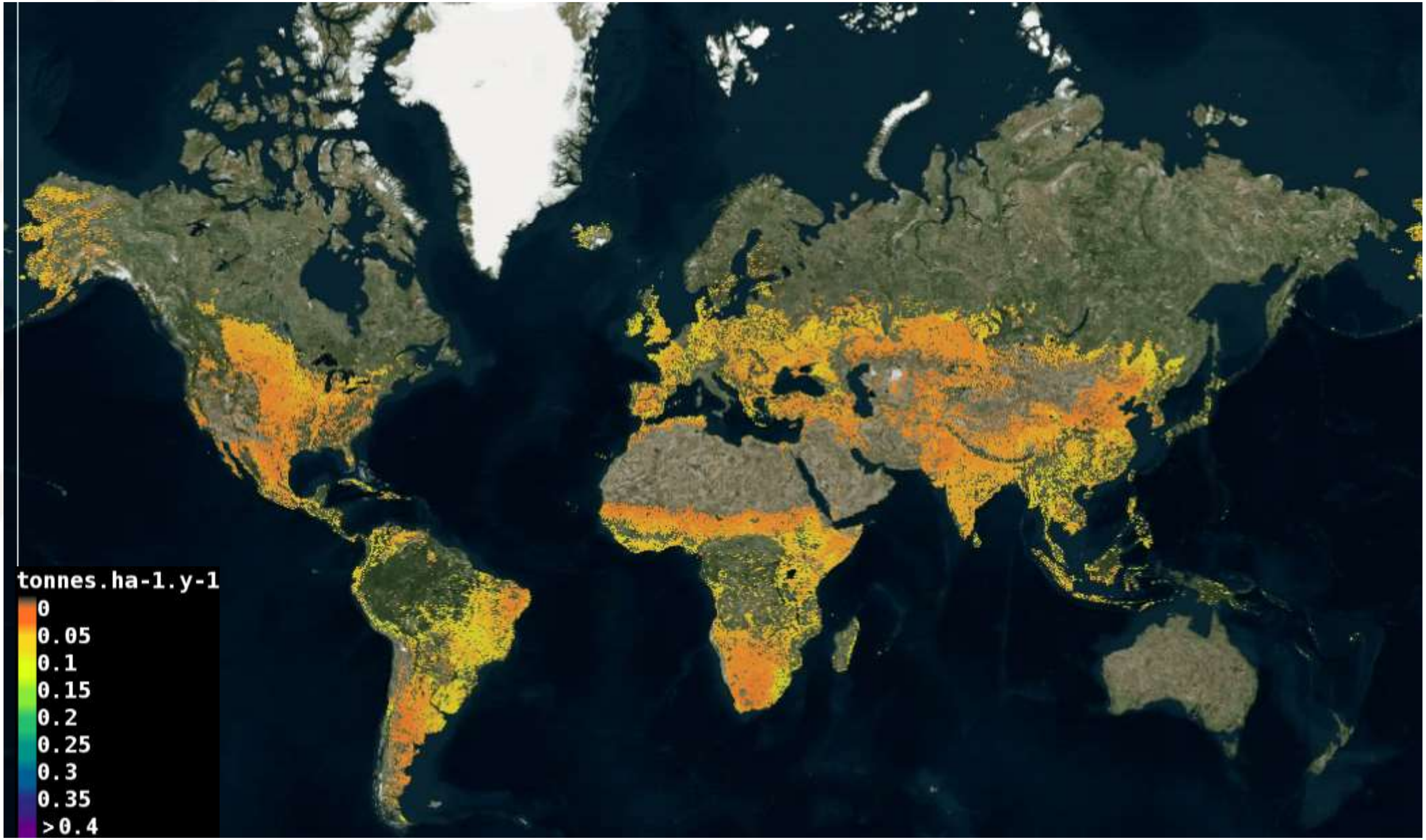
Relative sequestration rates tonnes.ha-1.y-1

SSM1 >> SSM3

GSOCseq v1.1

- SOC sequestration (tC/ha/yr) SSM 1-3
- Agricultural lands (croplands + grazing lands)
- 20-year period
- Depth: 0-30 cm
- 1 x 1 km resolution

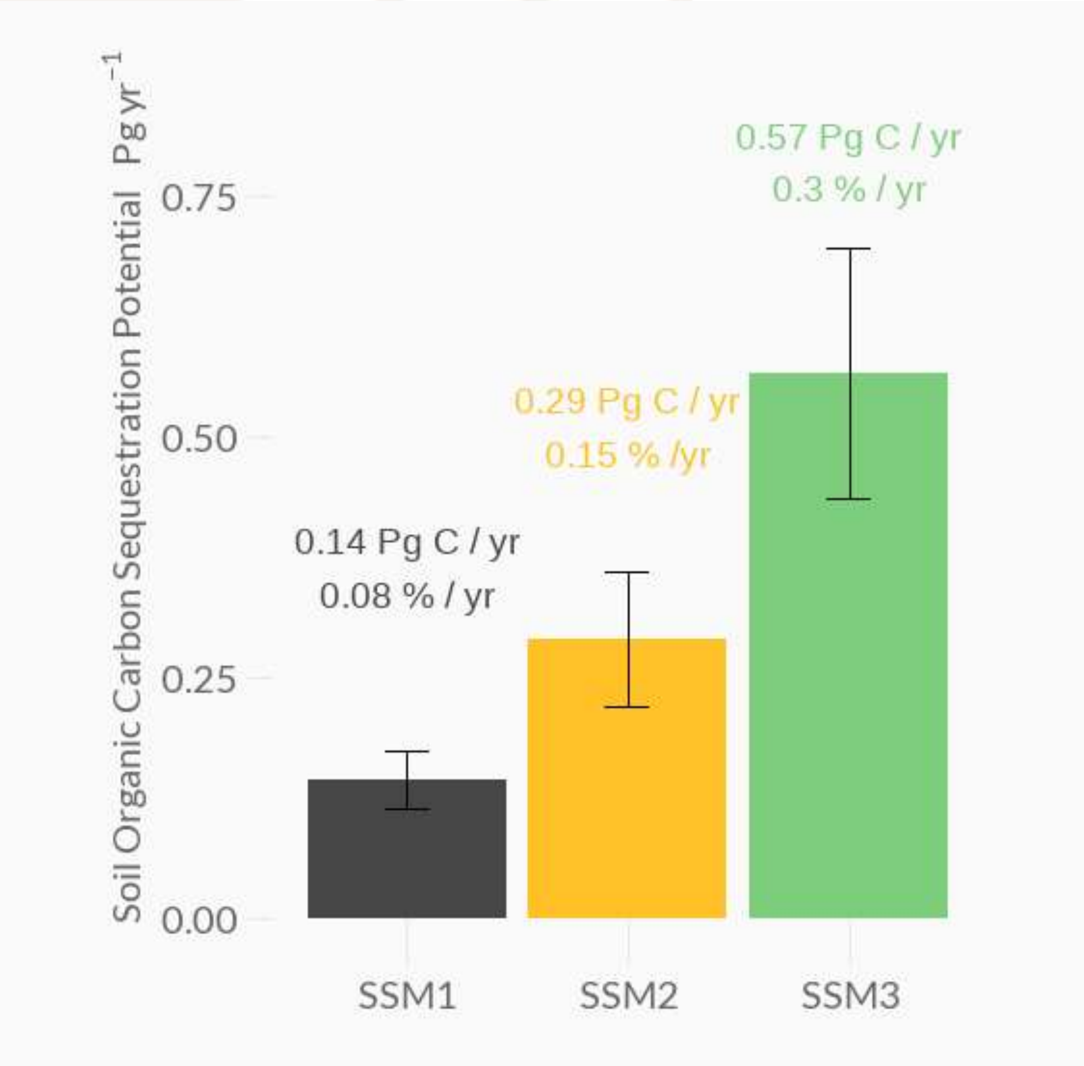
Continuously being updated!



GSOCseq v1.0.0 Uncertainties (%)

First results - Annual SOC sequestration*

***Excluding blank countries**

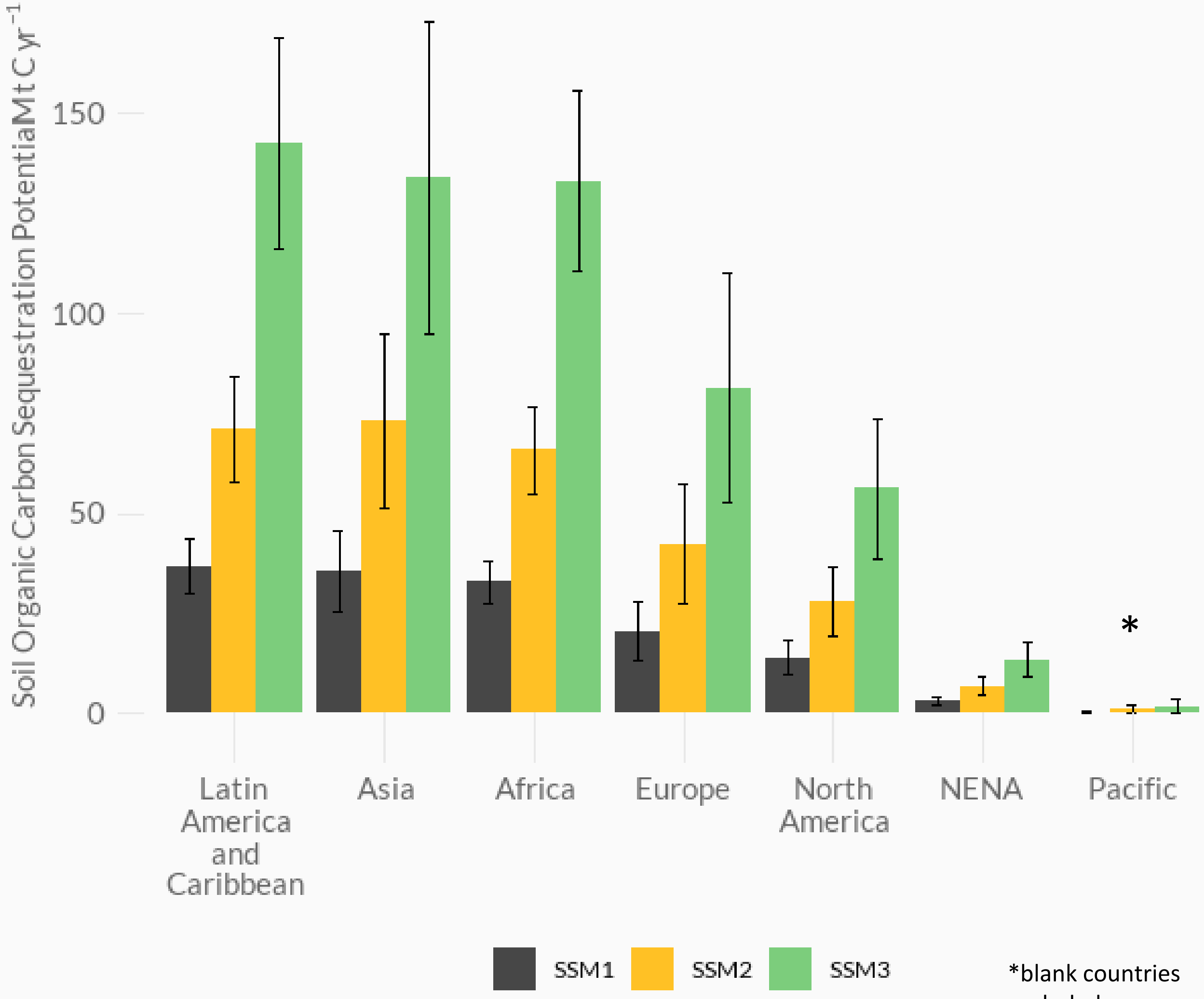


Previous estimates

Source	**Seq.rate Pg C.year^{-1}**
Paustian et al (2004)	**0.44 - 0.88**
Smith et al (2008)	**0.44 - 1.15**
Sommer and Bossio (2014) (croplands+grasslands)	**0.37 - 0.74**
Batjes et al (2019)	**0.32 - 1.01**
Lal et al (2018) (croplands+grasslands/shrublands)	**0.48 – 1.93**
Fuss et al (2018)	**0.54 – 1.36**

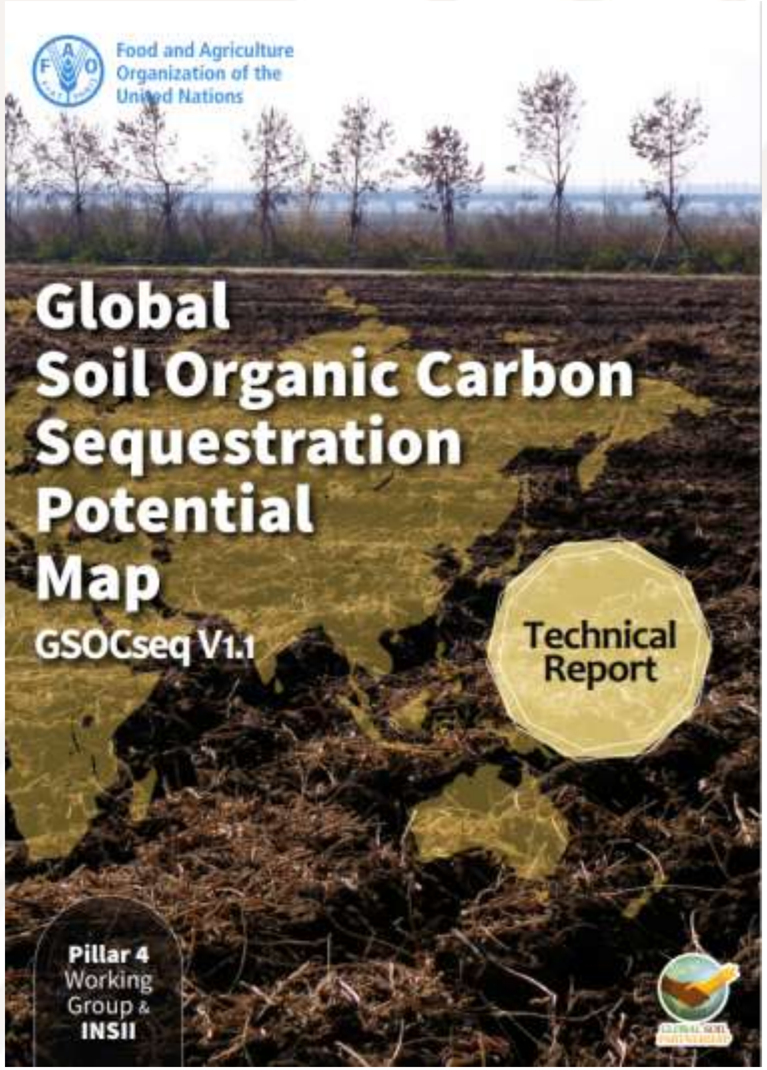
Potential uses - statistics

Which **climates**, **land uses**, **regions**, **countries** have greater SOC sequestration potential?



*blank countries excluded

GSOCseq v1.1 Technical Report



- To be periodically updated as more national maps are delivered

Summary. Inputs for the 3 Phases

Input data requirements				
Data	**Variables**	**Time series**	**Units**	**Type**
Climatic data	Monthly air temperature	1980-2000; 2001-2020 (or until last year available)	°C	Raster
	Monthly evapotranspiration (Penman-Monteith)	1980-2000; 2001-2020 (or until last year available)	mm	Raster
	Monthly precipitation + irrigation	1980-2000; 2001-2020 (or until last year available)	mm	Raster
Soil data	Topsoil clay content (0-30 cm)	-	%	Raster
	Current Soil organic carbon stocks (0-30 cm)	Latest version of national FAO-GSOC map	$tC\ ha^{-1}$	Raster
Land use/cover	Predominant land use/cover, re-classified into: Minimum: 4 default classes required by model: agricultural crops, grassland/shrubland/savannas ; forests; others Optimum: 11 classes defined in the FAO Global Land Cover - SHARE (GLC-SHARE)	Minimum: representative 2000-2020 (or last year available) Optimum: annual land use 2000 to 2020	1-11	Raster
	Monthly vegetation cover. Obtained from national statistics/local expert knowledge; or derived from NDVI or spectral indexes (see section 3.3.4)	Minimum: average 2015- 2020 (or last year available period) Optimum: monthly soil cover 2000 to 2020	0-1	Raster

What's next? GSOCseq v2

- The country-driven approach has allowed us to create a global network of national experts
- A dedicated GSOCseq Working Group was established
- Based on the implementation of the GSOCseq we were able to identify global needs and priorities to improve the data product

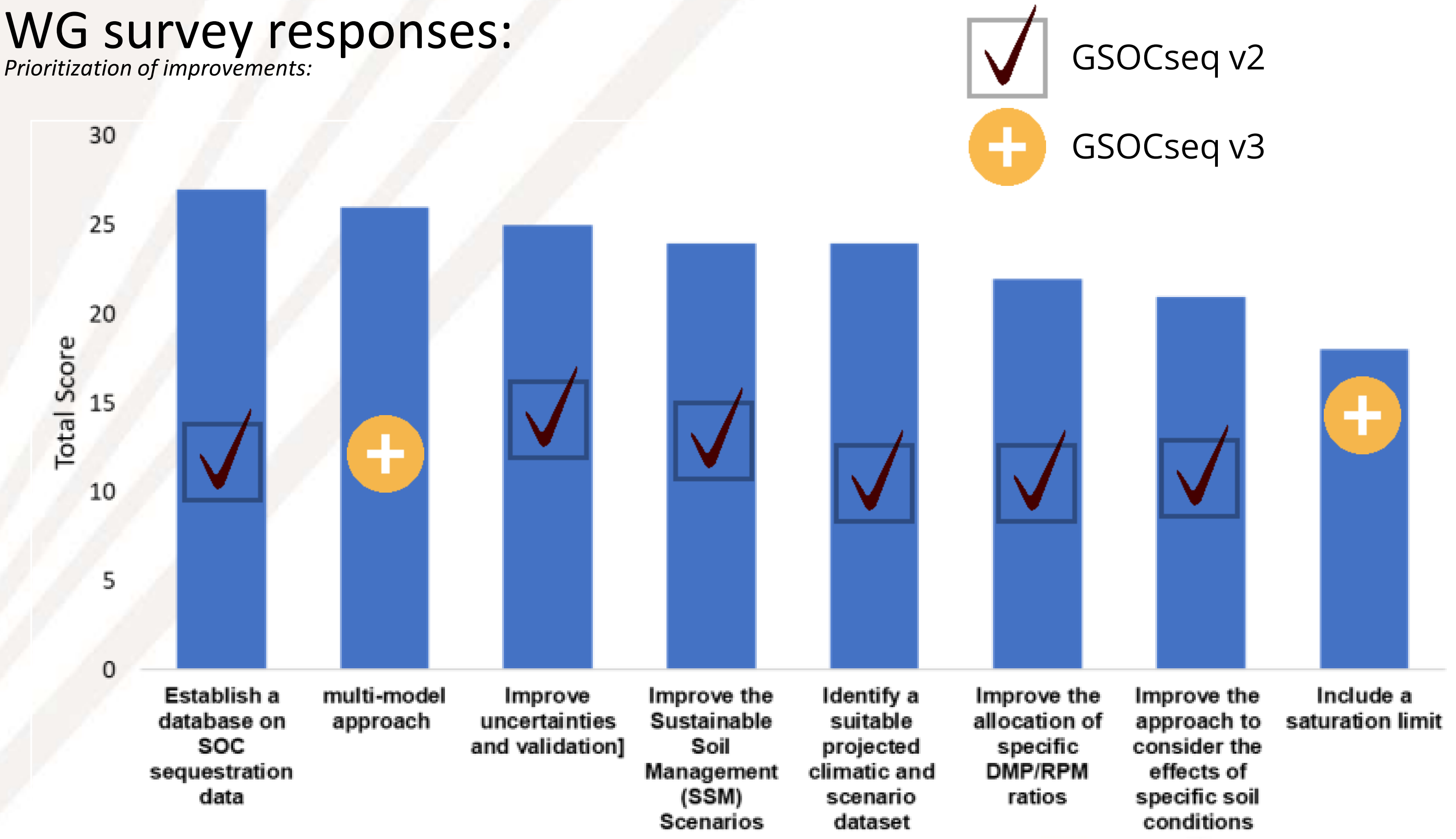
What's next? GSOCseq v2

- The GSOCseq WG was the first thematic WG created under INSII
- Its objective are:
  - Support the development of a way forward for the future versions of the GSOCseq:
    - Short-term improvements (GSOCseq v1.x): Provide technical guidance for the improvement of the current scripts and routines to generate a national GSOCseq product
    - Long-term improvements (GSOCseq v2.0): Provide technical guidance to select and prioritize potential improvements of the methodology (e.g. inclusion of climate change scenarios, country-specific scenarios)
  - Support the drafting of relevant publications
- 2 meetings so far:
- 1st Meeting of the GSOCseq Working Group (February 18 2022)
- 2nd Meeting of the GSOCseq Working Group (April 28 2022)

What's next? GSOCseq v2

WG survey responses:

Prioritization of improvements:



What's next? GSOCseq v2

- Improvement of the scripts:
  - From 16 distinct scripts (based on single steps) down to 9
  - Streamlined Input Data - GEE and R through the package rgee
  - Identification of a suitable climatic projection (downscaled future climate data from worldclim)
- Currently being implemented:
- Improvement of the SSM scenarios based on practices
  - A database of practices and their effect on SOC was compiled from the **Recarbonizing global soils - A technical manual of recommended management practices**
- A RECSOIL data collection app and database is currently being developed
- Improvement of the uncertainty assessment by incorporating the approach using the analytical Taylor Francis approach (Martin et al., 2021)
- Improved DPM/RPM ratio allocation (grasslands)
- Improved gap-fill layer

Thank you!

For any question: Isabel.Luotto@fao.org