Global Soil Organic Carbon Sequestration Potential Map

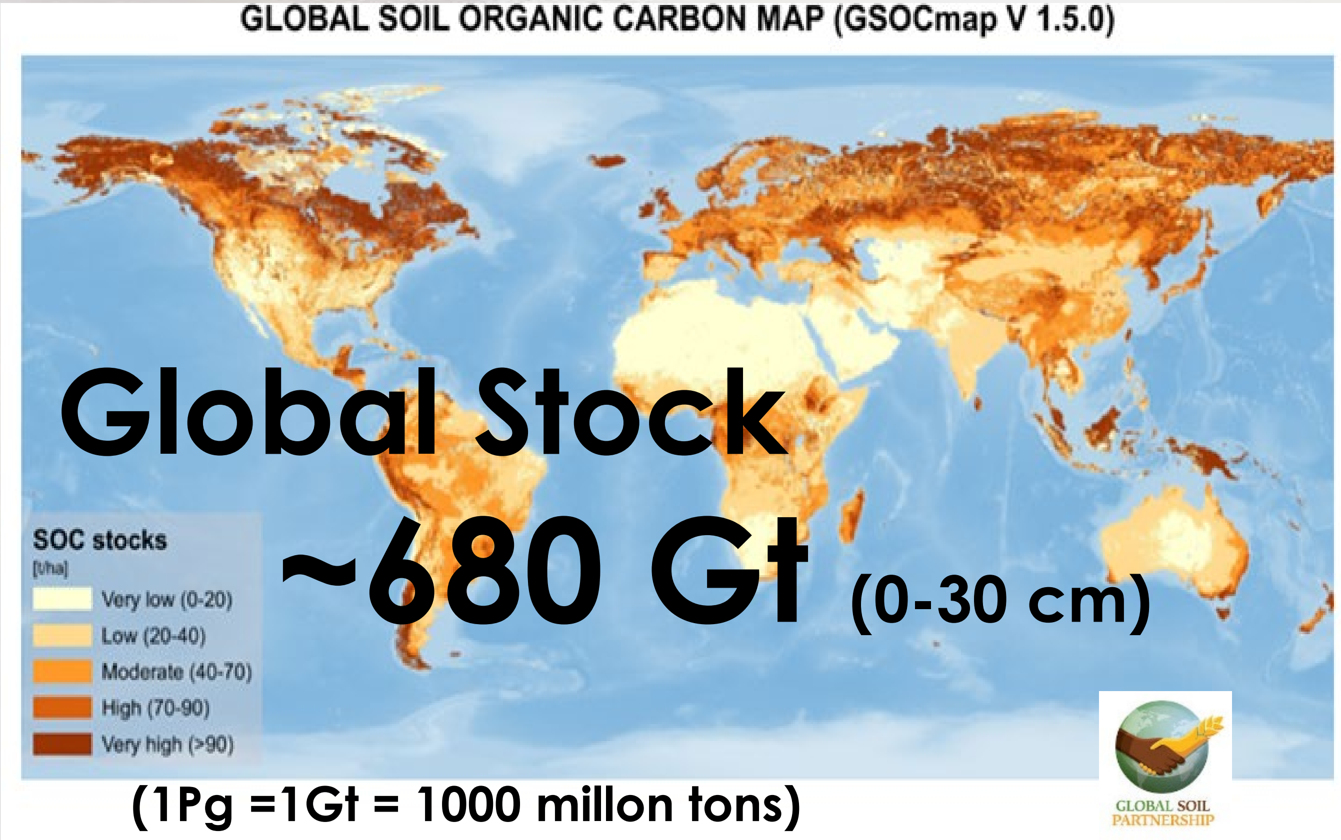
GSOCseq

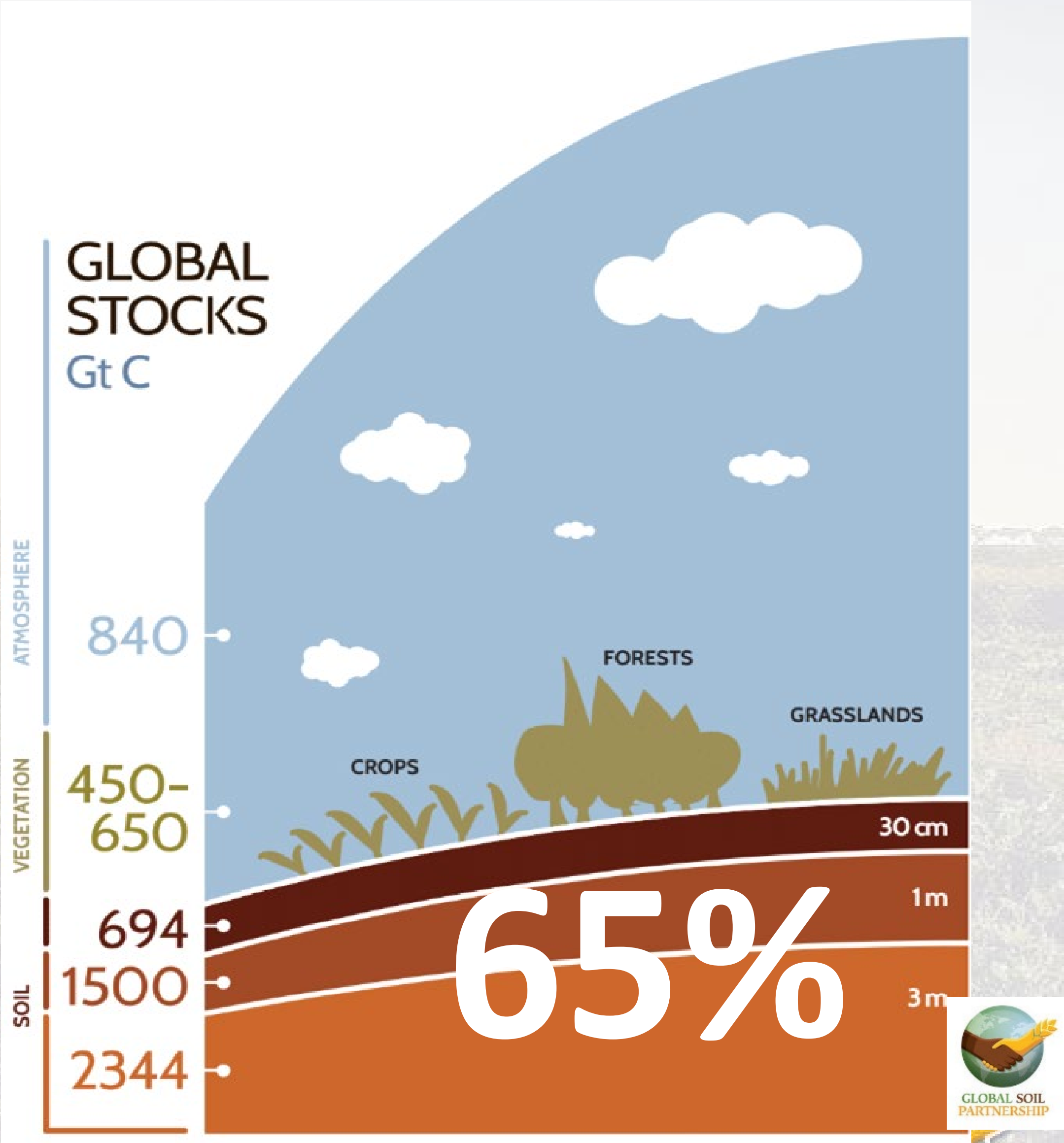
Guillermo Peralta
Luciano Di Paolo
Isabel Luotto
Marcos Angelini
Yusuf Yigini

GLOBAL SOIL PARTNERSHIP

Technical Workshops. 2022

Soil Organic Carbon is the largest terrestial carbon pool



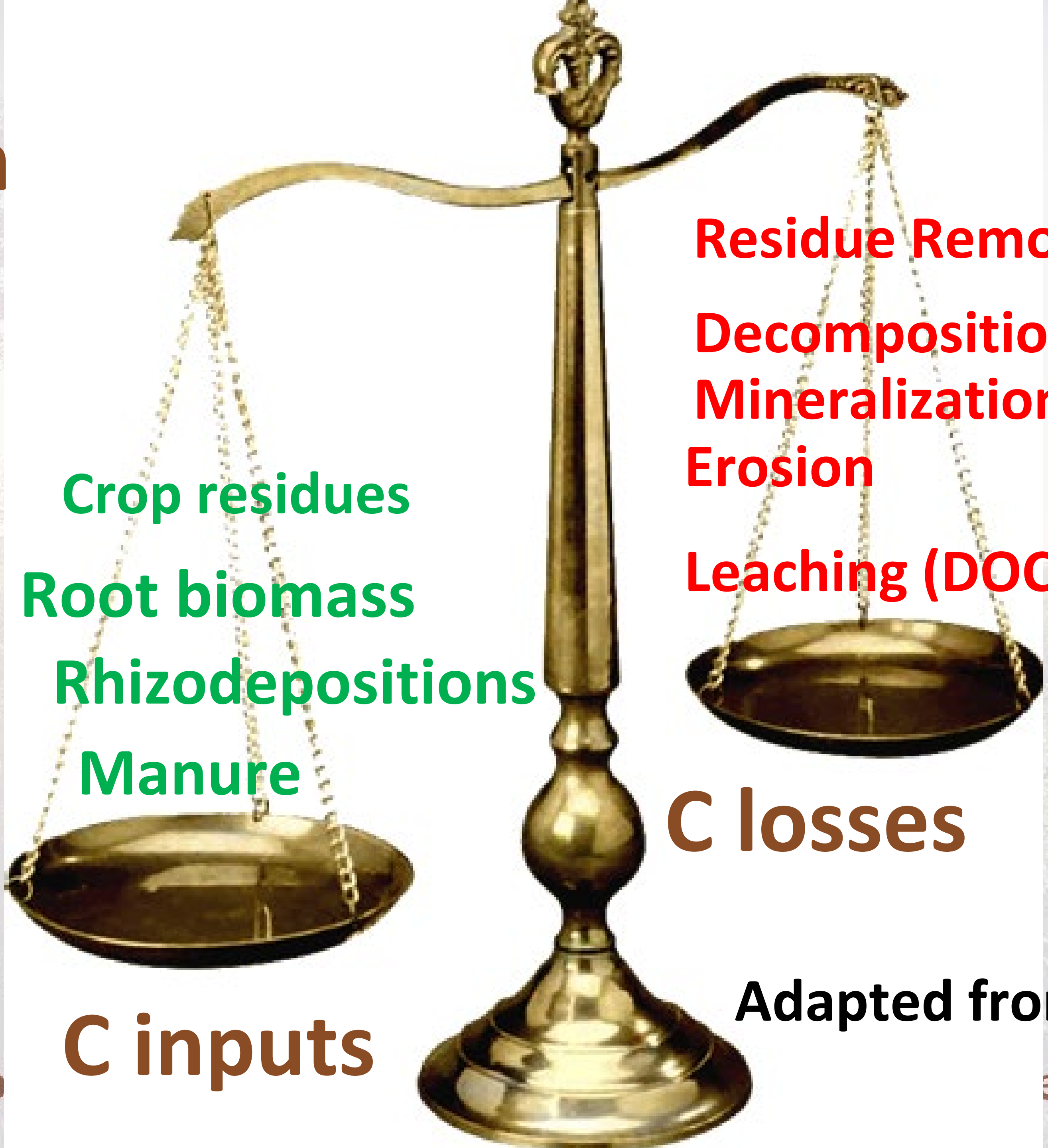


- Due to the magnitude of SOC pool, small increases in SOC stocks can transform soils into potential carbon sinks (Paustian et al., 2016)

- CO_2 sequestration as SOC through sustainable managment practices has been outlined as one of the most cost-effective practices to mitigate GHG emissions (Smith et al, 2008; Lal et al., 2018; IPCC, 2019; Smith et al., 2020).

- Besides other benefits linked to SOC increase: soil structure, water infiltration and retention, nutrient cycling, etc

SOC sequestration



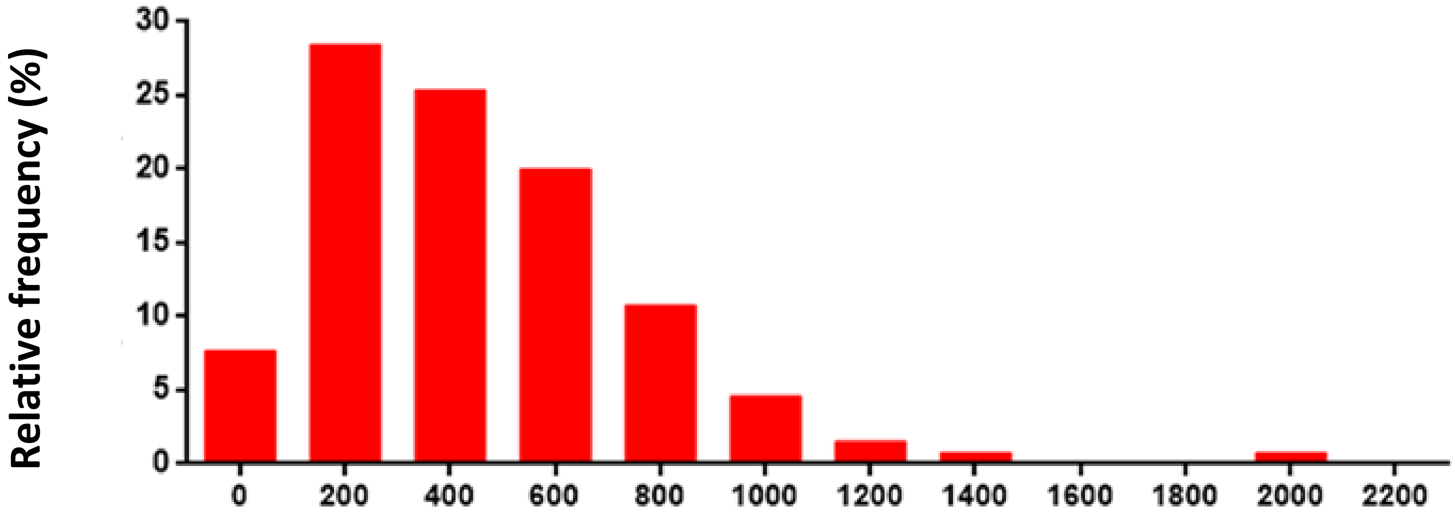
Adapted from Lal, 2020

Management practices	Country	Depth observed	Carbon sequestration rates[b] t C ha^{-1} yr^{-1}	Average C stock[a] t C ha^{-1}	Period of observation	References
Arable land						
Organic amendment	China	Plough layer, 0–20 cm for dry cropland and 0–15 cm for paddy soil	0.62	24.4	*6 to 25 years, 14.4 years on average	Wang e
Organic amendment	China	Plough layer	0.54	24.4	*3 to 25 years	Jin et al
Organic amendment combined with inorganic fertilizer	China	Plough layer, 0–20 cm for dry cropland and 0–15 cm for paddy soil	0.62 0.69 0.89	24.4	*3 to 25 years	Jin et al Zhu et a Wang e
Compost addition	S. Korea	0–30 cm paddy soils	0.24	40.5	42 years	Lee et a
Compost addition with inorganic fertilizer	S. Korea	0–30 cm, paddy soils	0.39	40.5	42 years	Lee et a
Compost addition	Taiwan	0–15 cm	0.46–1.00	36	*13–20 years	Wei et Wei et
Compost with inorganic fertilizer	Taiwan	0–15 cm	0.40–0.80	37.4	*20 years	Wei et Wei et
Farmyard manure (@0.16 Mg C/ha/yr)	Belgium	0–25 cm	0.45 ± 0.14	50	*20 years	Buysse
Farmyard manure/crop residue	Nigeria	Topsoil	0.10–0.30	33.4	*50 years	
Inorganic fertilizer with straw return	Indonesia	0–15 cm, paddy soils	0.52 ± 0.16	17.9	40 years	
Straw return with Inorganic fertilizer	Indonesia	0–15 cm, paddy soils	0.47	17.9	*3 years	
Inorganic fertilizer	S. Korea	0–15 cm, paddy soils	0.32 ± 0.29	27.3	8 years	
Straw return	China	Plough layer	0.57–0.60	27.6	*3 to 25 years	
Rice-Rice with NPK	India	0–20 cm	0.23	31.3	36 years	
Rice-Rice with NPK + compost	India	0–20 cm	0.41	31.3	36 years	
Rice-Wheat with NPK	India	0–60 cm	0.66	34.4	19 years	
Rice-Wheat with NPK + Farm yard manure (FYM)	India	0–60 cm	0.99	34.4	19 years	
Rice-Wheat with NPK + Paddy straw	India	0–60 cm	0.89	34.4	19 years	
Rice-Wheat with NPK + Green manuring	India	0–60 cm	0.82	34.4	19 years	
Inorganic fertilizer	India	0–15 cm	0.16	13.3	6–32 years	
Inorganic fertilizer + FYM	India	0–15 cm	0.33	13.3	6–32 years	
Residue incorporation	Nigeria	0–15 cm	0.24	20	*18 years	
Stubble retention	Australia	0–15 cm	0.19 ± 0.08	21.2	*	
Stubble retention	Australia	0–10 cm	0.147 ± 0.059	18.3	*4 to 40 y	
No till	China	Plough layer	0.16–0.51		3 to 25 years	
No till	France	0–30 cm, Wheat-corn rotation	0.2 ± 0.13	51.6	20 years	
No till	UK	Topsoil	0.31 ± 0.2	80	5–23 years	
No till	USA	0–20 or 0–30 cm	0.4 ± 0.61[c]	53 ± 25.2	12–34 years	
No till plus cover crops	USA (southeast)	0–20 cm	0.45 ± 0.04	25.5 ± 0.9	11 ± 1 years	
Conventional till to no-till	Canada	0–30 cm	0.05–0.16	75	20 years	
Reduced use of summer fallow	Canada	0–30 cm	0.30	75	20 years	
Reduced tillage	Australia	0–15 cm	0.34 ± 0.06	21.2	*Various, 4 to 42 years	
Reduced tillage	Belgium	0–60 cm	0		20 years	
Conservation tillage	Australia	0–10 cm	0.15 ± 0.028	18.3	4 to 40 years	
Conservation tillage	France	0–25 cm	0.10	51.6	28 years	
Crop rotation	Australia	0–15 cm	0.20 ± 0.04	21.2	Various, 4 to 42 years	
Crop rotation	France	0–30 cm	0.16 ± 0.08	51.6	20 years	
Crop rotation with perennial grasses	Russia	Plough layer	0.03–0.08	32.3	*5 years	
Conversion to ley farming	England	0–23 cm	0.20	80	30 years	
Conversion of annual cropping to crop + ley rotation	USA	0–30 cm	0.5	78	30 years	[illegible]
Grassland						
Cropping to pasture	Australia	0–15 cm	0.30–0.60	27.5	4 to 42 years	Sanden
Cropping to pasture	Australia	Pasture rotation, 0–30 cm from 33% to 67% pasture	0.22–0.76	43	10 years	Chan et
Cropping to pasture	Australia	Pasture to improved pasture	0.76	43	10 years	Chan et
Cropping to pasture	Australia	0–30 cm	0.78	31	4.7 years	Badgery
Cropping to pasture	France	0–30 cm	0.49 ± 0.26	51.6	20 years	Arrouays et al. (2002a,b)
Cropping to pasture	England	0–23 cm	0.51	80	35 years	Goulding and Poulton (2005)
Pasture	Australia	0–10 cm	0.132 ± 0.054	18.3	4 to 40 years	Lam et al. (2013)
Pasture	Australia	0–30 cm, perennial and annual pasture	0.759 ± 0.049	35	7 years	Chan et al. (2011)

<0.1 to 2.2 t C ha^{-1} year^{-1}

(Poepleau and Don, 2015; Kampf et al., 2016; Minasny et al., 2017; Conant et al., 2017; Paustian et al., 2016; Paustian et al., 2019).

75 studies



SOC sequestration rate (kg C. ha-1 . yr-1)

Food and Agriculture Organization of the United Nations

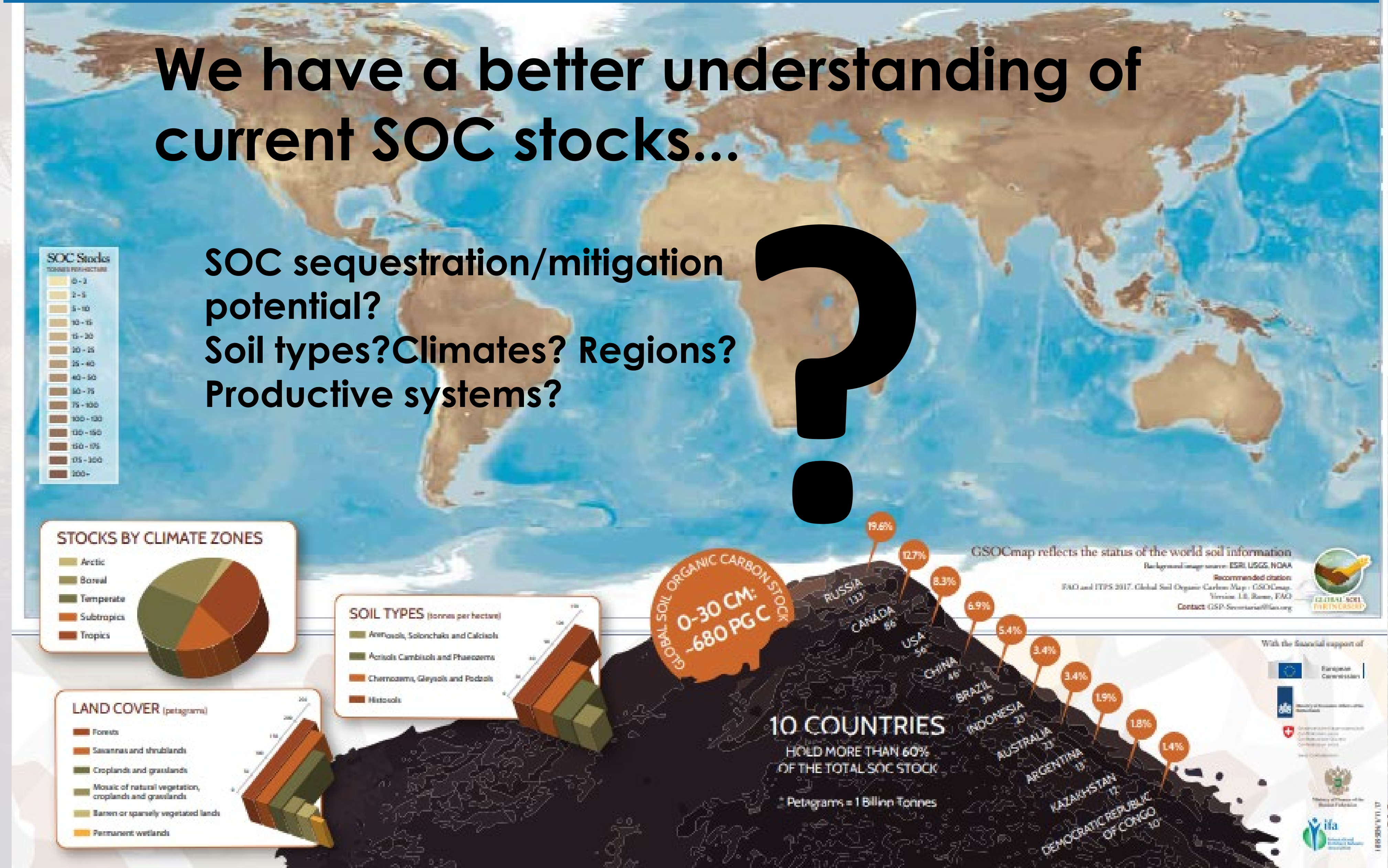
GLOSIS - GSOCmap (v1.5.0)

Global Soil Organic Carbon Map. Contributing Countries.

We have a better understanding of current SOC stocks...

SOC sequestration/mitigation potential?
Soil types?Climates? Regions?
Productive systems?

?



Why GSOC$_{seq}$ map?

Objective

- Identify which regions and productive systems show higher potential to increase SOC stocks, following harmonized and standardized procedures among countries

establish priorities for research and public and private policies

Support countries to develop Climate change adaptation and mitigation strategies, and sustainable development

¿Why $GSOC_{seq}$ map?

Country-Driven GSOCseq product. Strengths:

•Local expertise, based on best available local data ("bottom-up")

•Inclusive process, involving specialists from different fields and institutions

•Continuous improvement process ; "living product"

How is the GSOCseq Country-driven process?

FAO Members /GSP partners request

Collection of feedback

Action on the ground

Monitoring sites to validate results

Implementation SSM practices

Country-driven GSOCseq

2019

Methodology

Through the support of the GSP's technical networks

Taking into considerations potential data and computational limitations

2020

Technical specifications and country guidelines

Reviewed INSII, ITPS, CIRCASA, 4p1000, UNCCD

2020-21

Capacity Building Program

Online Technical Manual

Online regional trainings

2021

National Maps and Submissions

Permanently updated Subsmissions

promoting sustainable soil management for all

GLOBAL SOIL PARTNERSHIP

Country Driven GSOCseq. Workshops

- **Trainings/exchange workshops**
- **Harmonization of procedures and methodologies among countries**
- **Integration of experts among countries and within each country**

Agenda

DAY 1 (3h) - Opening and Introduction

1. High-Level opening (Dr. Park Joungyoon, AFACI Senior Deputy Secretary General, AFACI Secretariat)- 10'
2. Introduction: The GSOCseq Initiative (importance, the process, benefits, timeline), General framework (BAU, SSM1-SSM2-SSM3, Meta-Analysis), Product specifications, discussion and feedback on national capacities

DAY 2 (3h) - Introduction to sequestration modelling

1. Introduction to sequestration modelling (RothC Basics), Input data requirements; uncertainties, software and tools (R, QGIS and Google Earth Engine to be used during the training)
2. Introduction to the R language and RStudio
3. Input data preparation: running Scripts 0 to 9

DAY 3 (3h) – Input data preparation

1. Input data preparation (continuation of Day 2): running Scripts 0 to 9
2. Harmonization of spatial layers

DAY 4 (3h) – Modeling and Mapping SOC sequestration Potential

1. Modeling and Mapping stage: running Scripts 9-16
2. Hands-on break out room session: applying the methodology to national data

DAY 5 (3h) - Review and Implementation

1. Review and interpretation of the results and QA
2. Hands-on break out room session

How? Framework

1 **Technical Specifications**
https://www.fao.org/documents/card/es/c/cb0353en/

2 **Technical Manual**
https://fao-gsp.github.io/GSOCseq/

Contributors and reviewers

P4WG - Pillar 4 Working Group

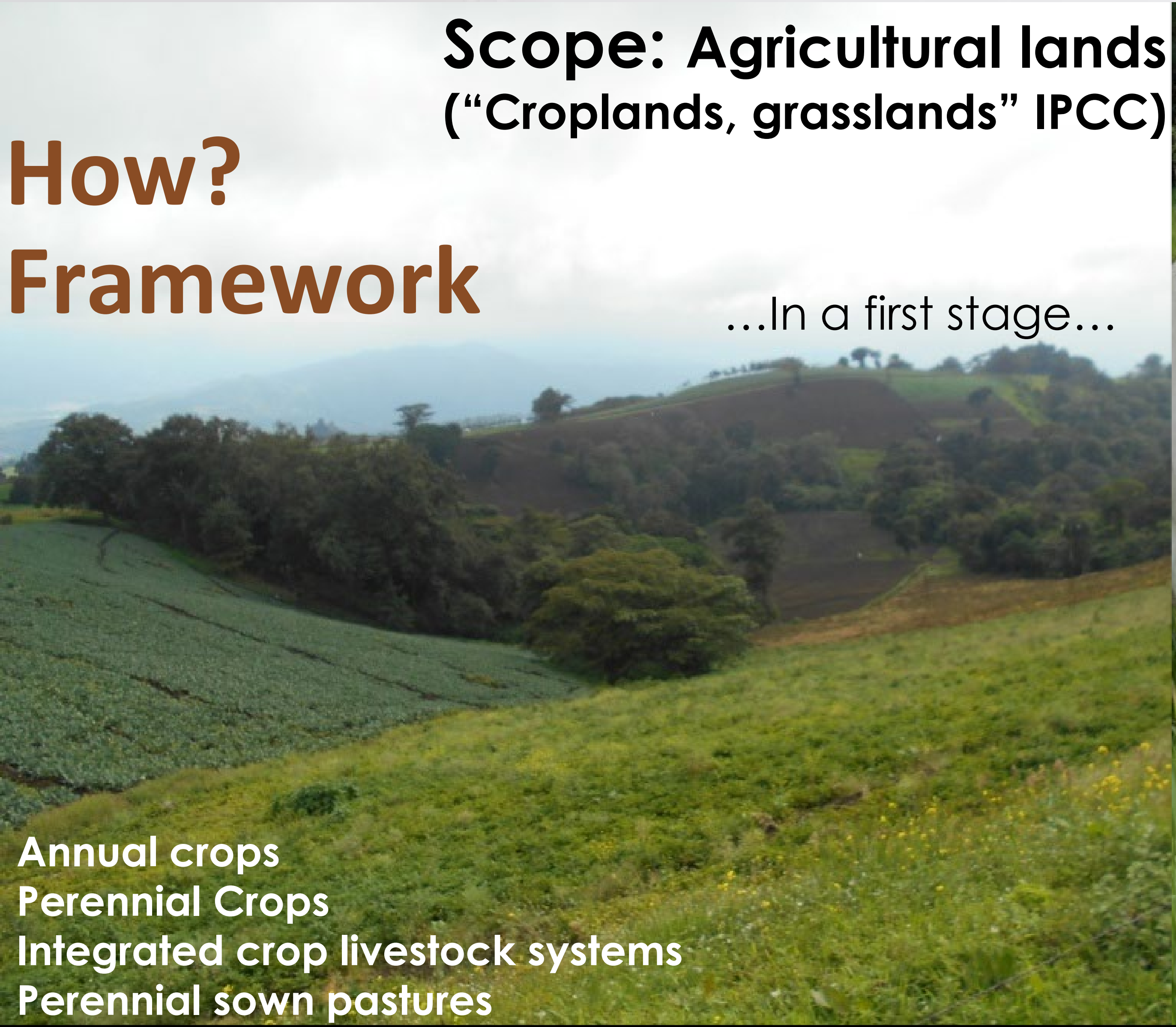
INSII - International Network of Soil Information Institutions

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



Scope: Agricultural lands
("Croplands, grasslands" IPCC)

How? Framework

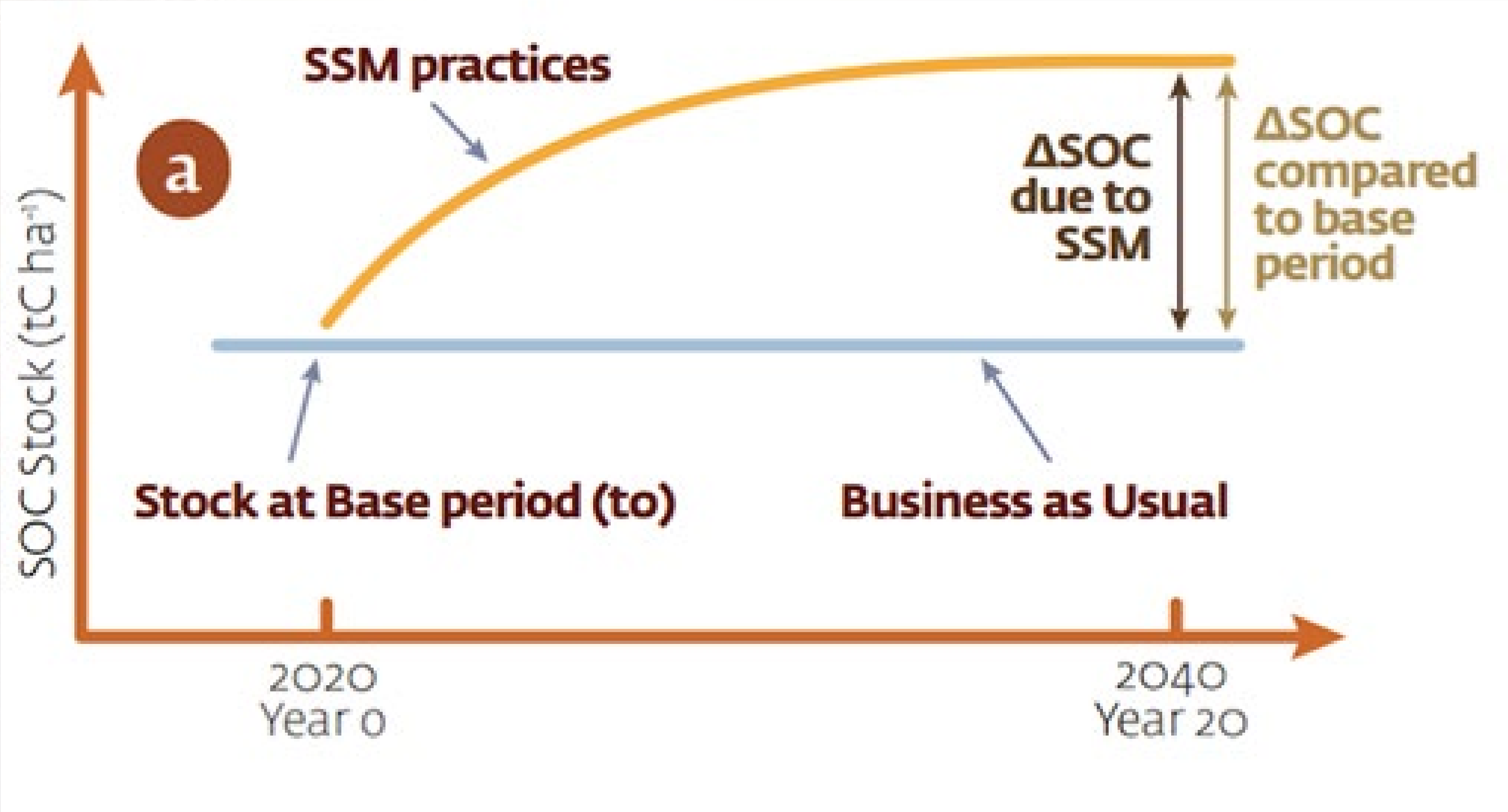
...In a first stage...

Annual crops
Perennial Crops
Integrated crop livestock systems
Perennial sown pastures

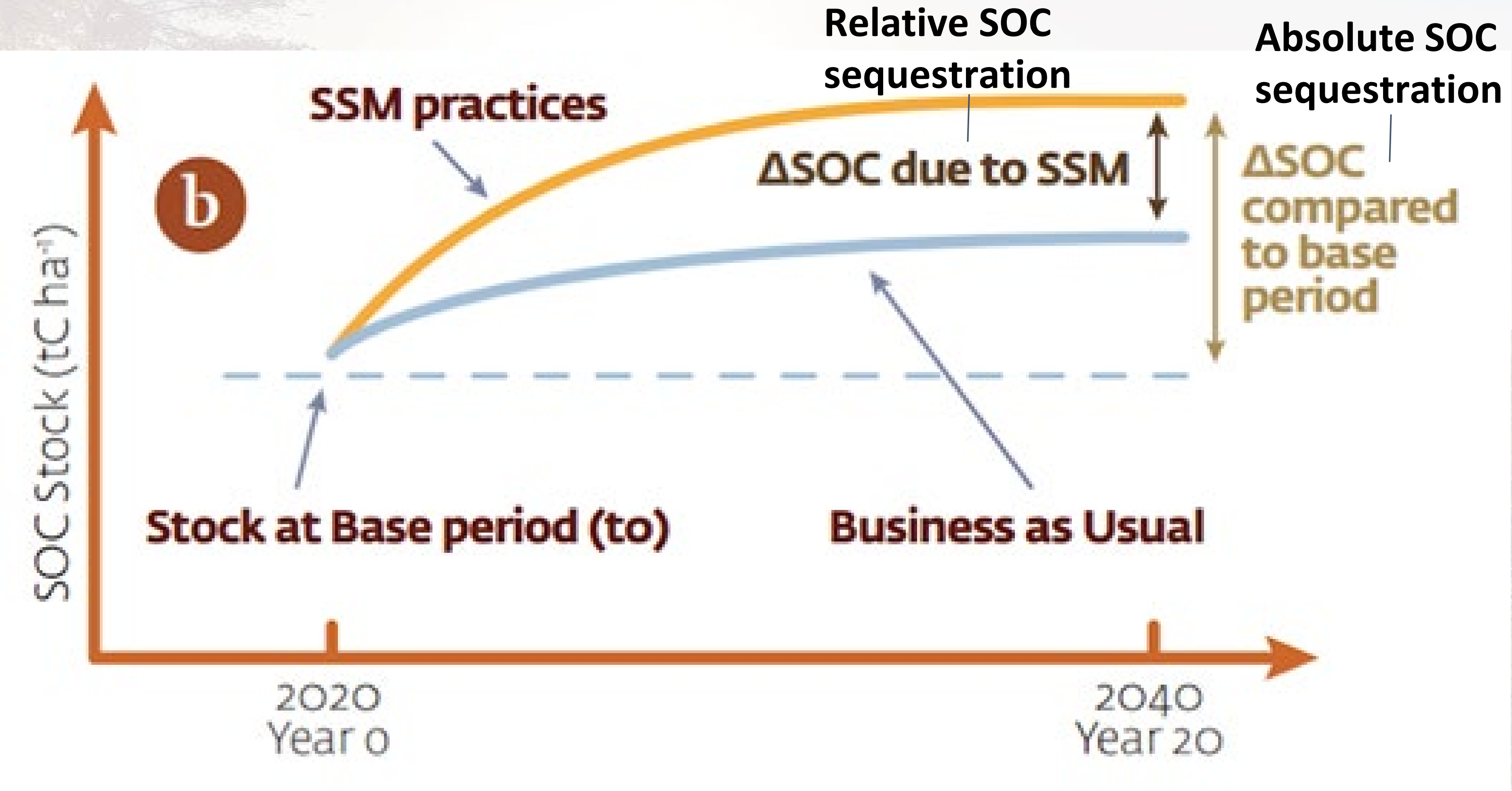
Grasslands, shrublands and savannas (grazing lands) Agro forestry; silvo pastoril

Magnitude of global agricultural area,
Annual management; Higher probability to implement SSM practices
Linked to programmes like RECSOIL (encourage SSM by farmers)

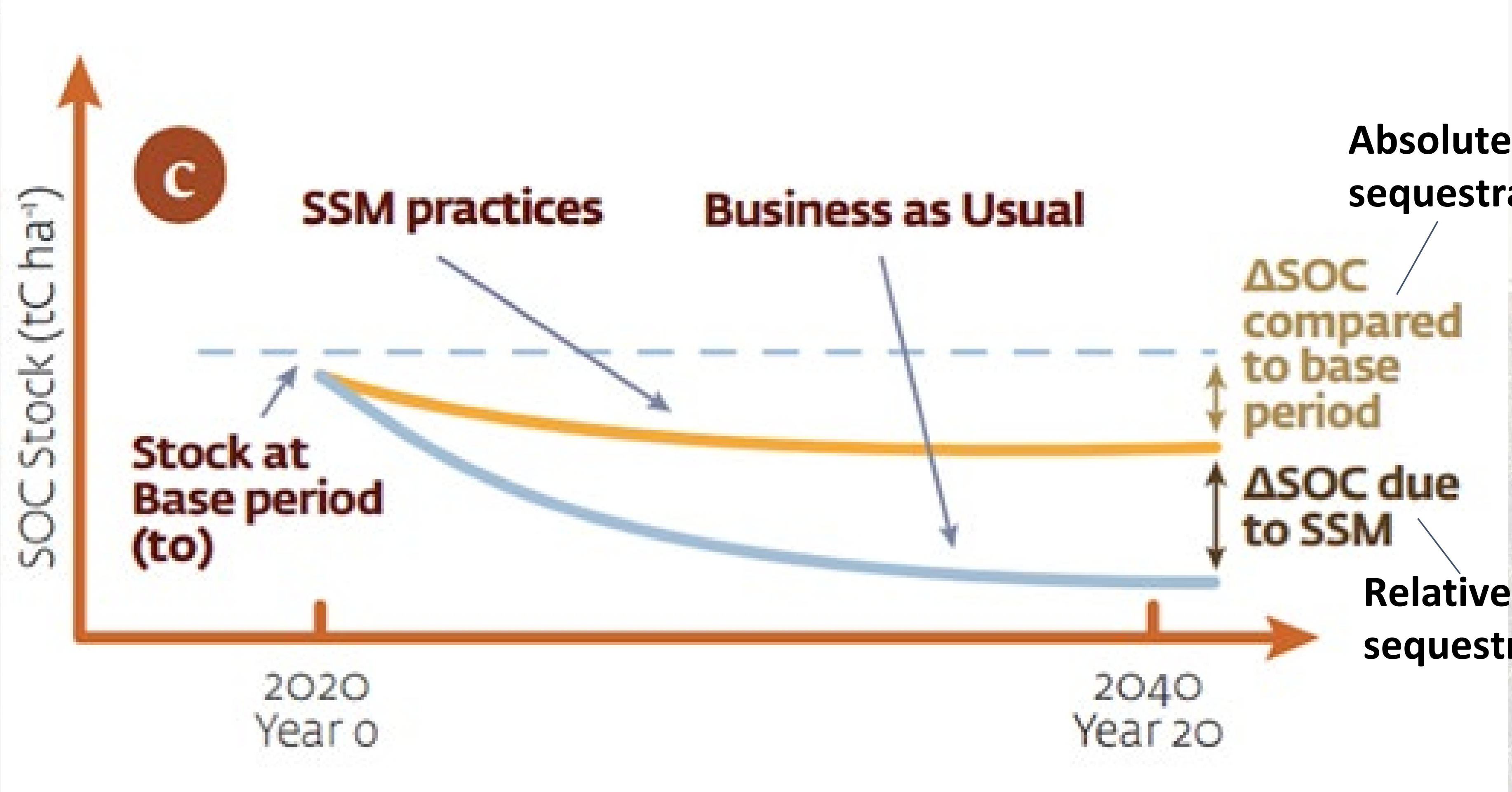
How?
Framework - SOC sequestration



How?
Framework



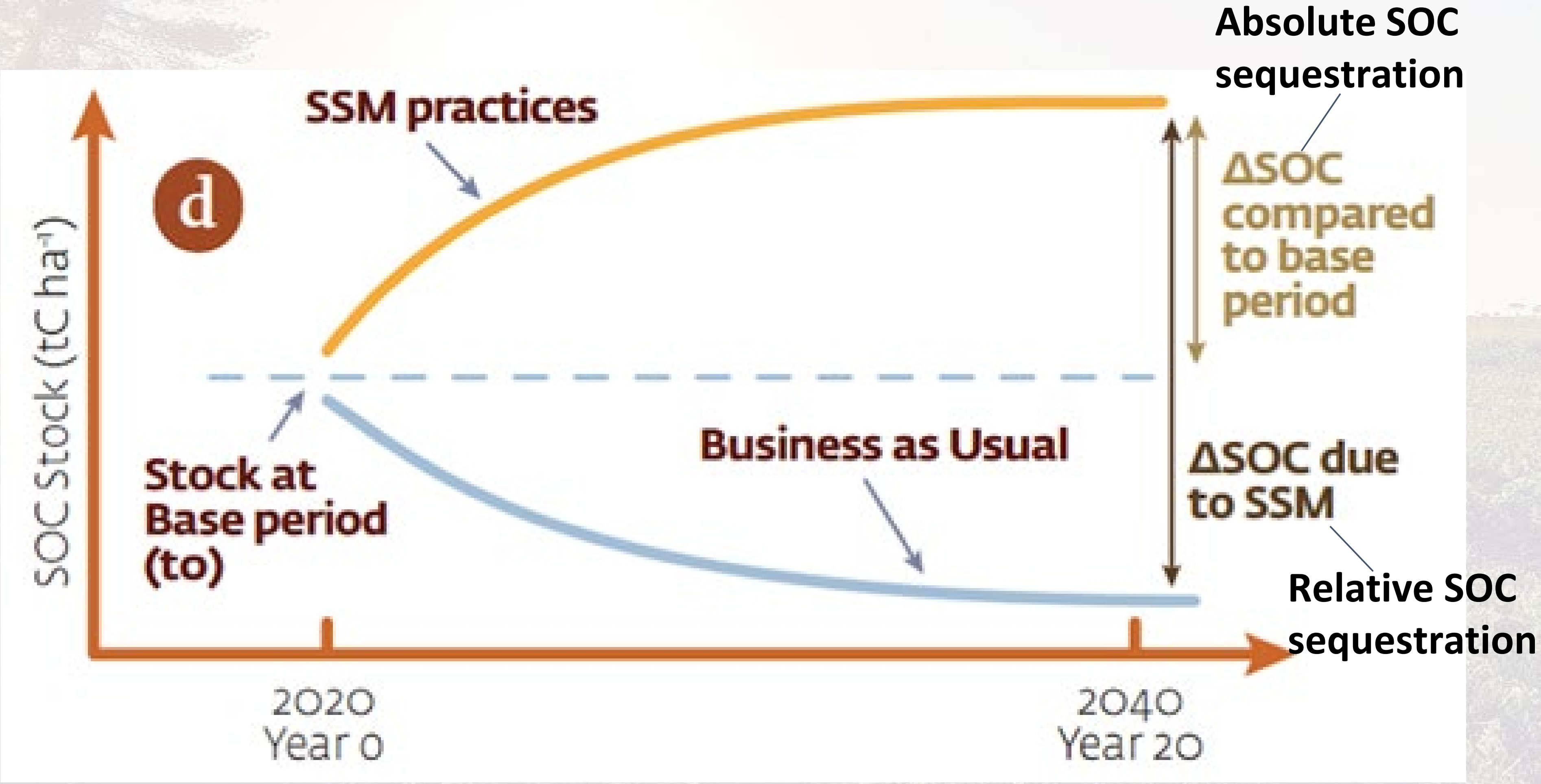
How?
Framework



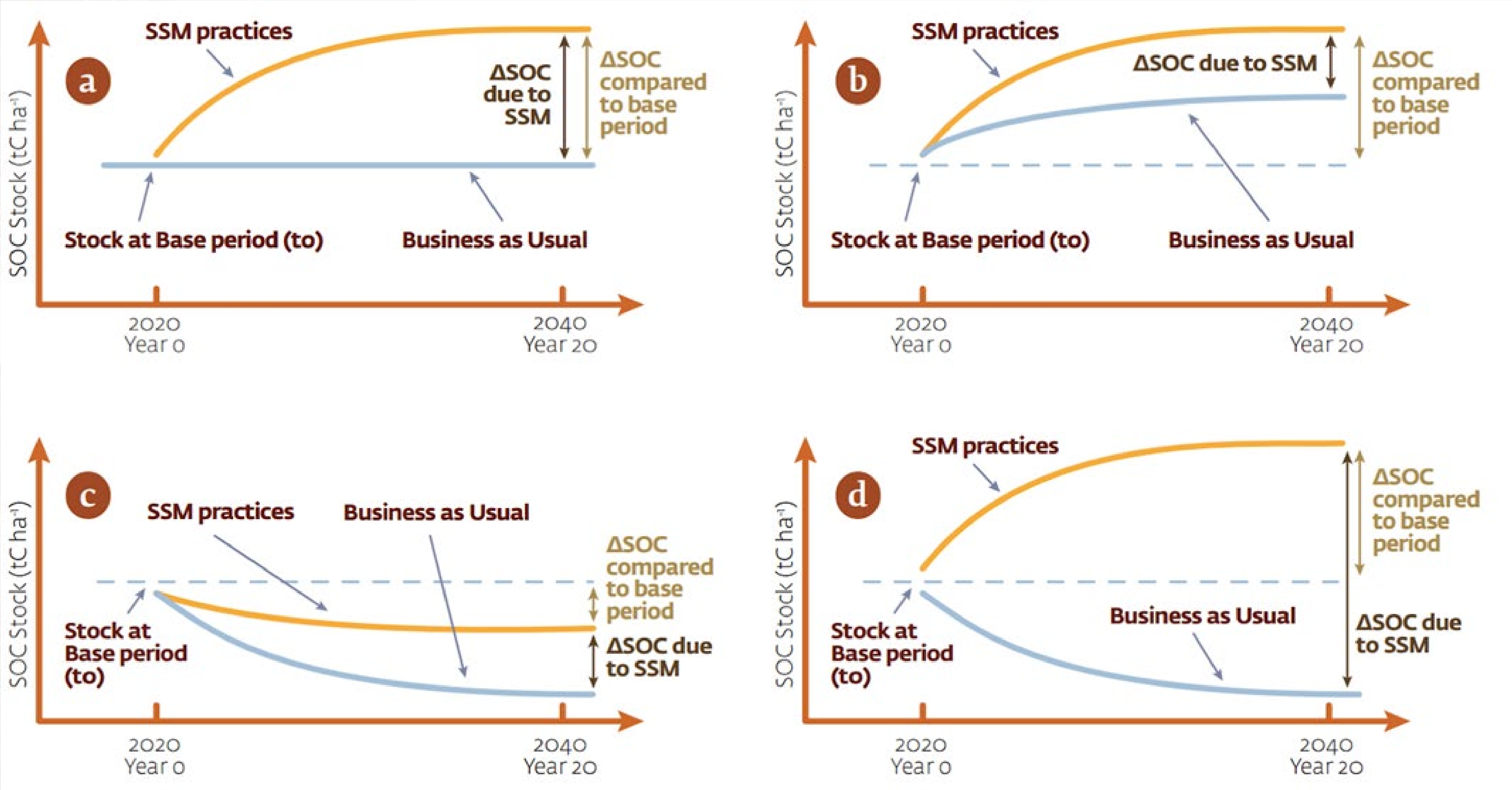
Absolute SOC sequestration

Relative SOC sequestration

How?
Framework



Absolute and relative SOC sequestration



SOC sequestration (Difference) = Δ SOC in 20 years

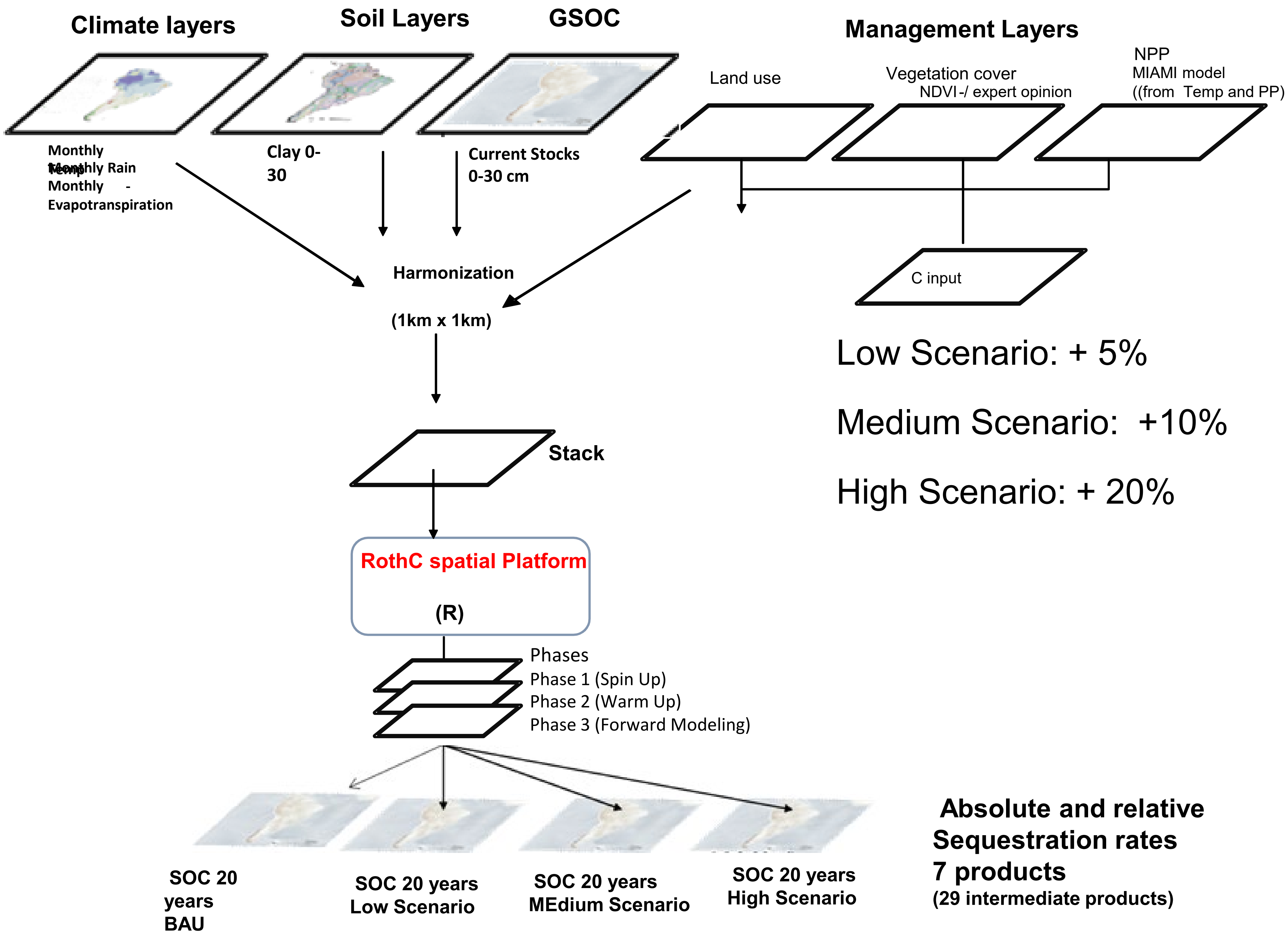
Annual Sequestration rate = Δ SOC / 20 years

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

How?
Framework -Summary

- 20-year projection
- After the adoption of SSM that increase C inputs
- 0-30 cm Depth (GSOC, IPCC, Activity data to validate the model)
- Absolute and relative SOC sequestration rates, average 20 years
- In current agricultural lands (Each country can model preferred land uses, restoration, etc.)


Climate layers
Soil Layers
GSOC
Management Layers
Land use
Vegetation cover
NDVI -/ expert opinion
NPP
MIAMI model
((from Temp and PP)
Monthly Temp
Monthly Rain
Monthly - Evapotranspiration
Clay 0-30
Current Stocks 0-30 cm
Harmonization
(1km x 1km)
C input
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

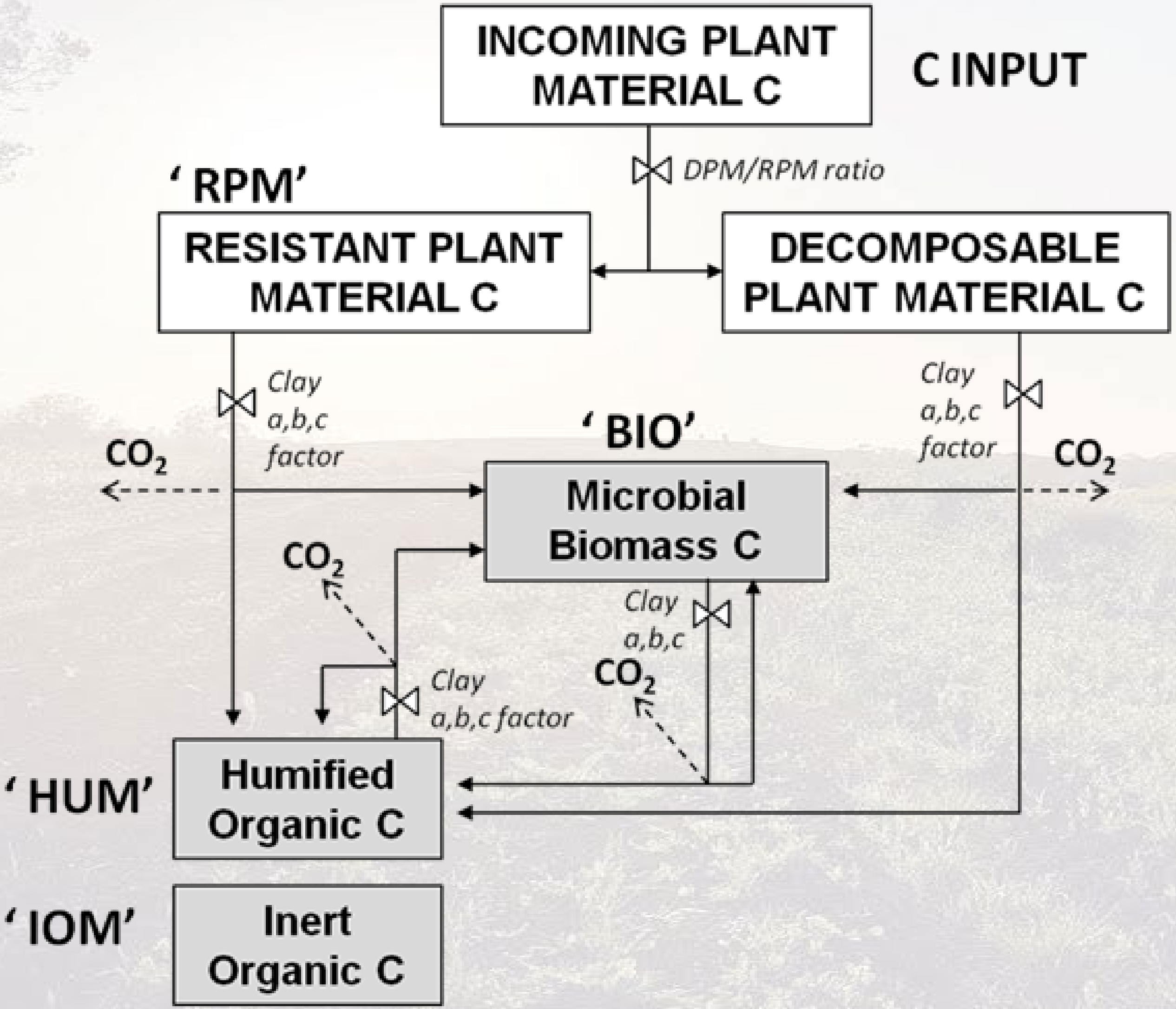
Soil

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)	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



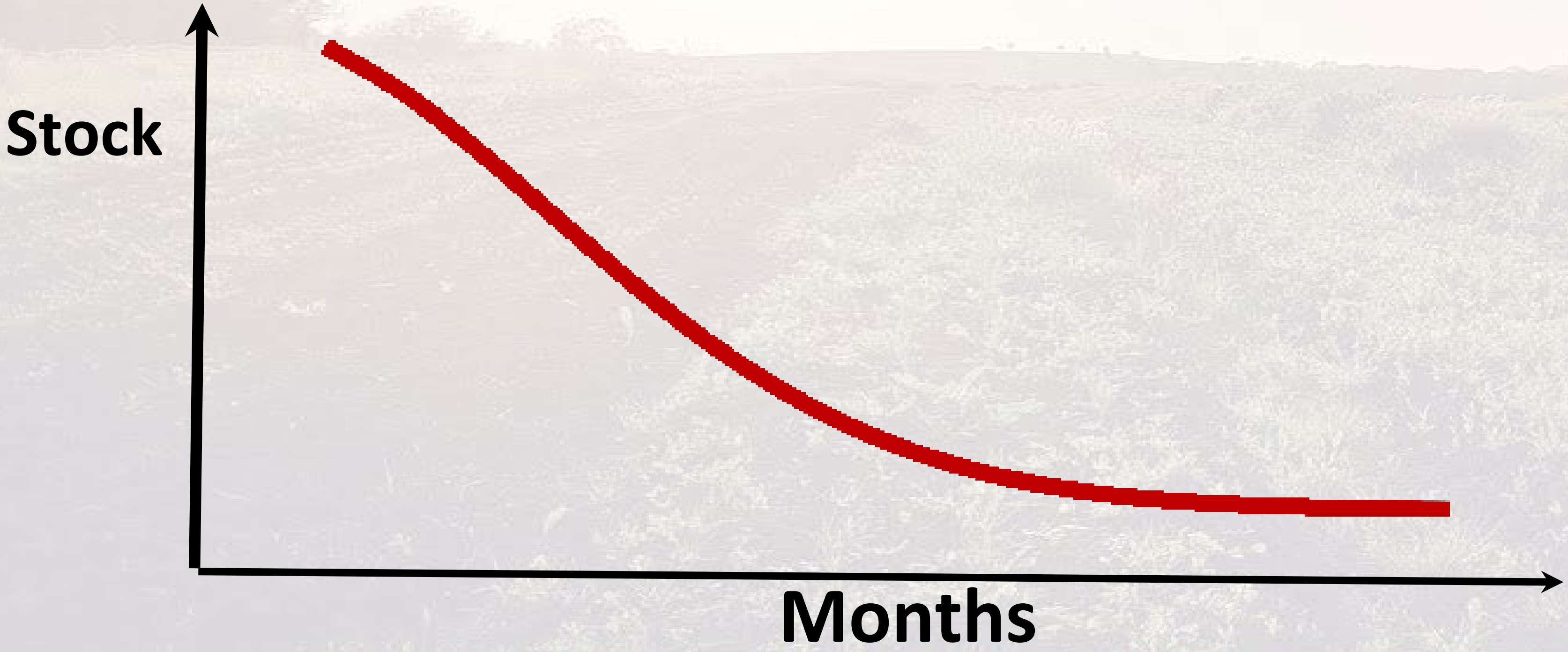
SOC dynamics in RothC

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 .... α

SOC dynamics in RothC

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

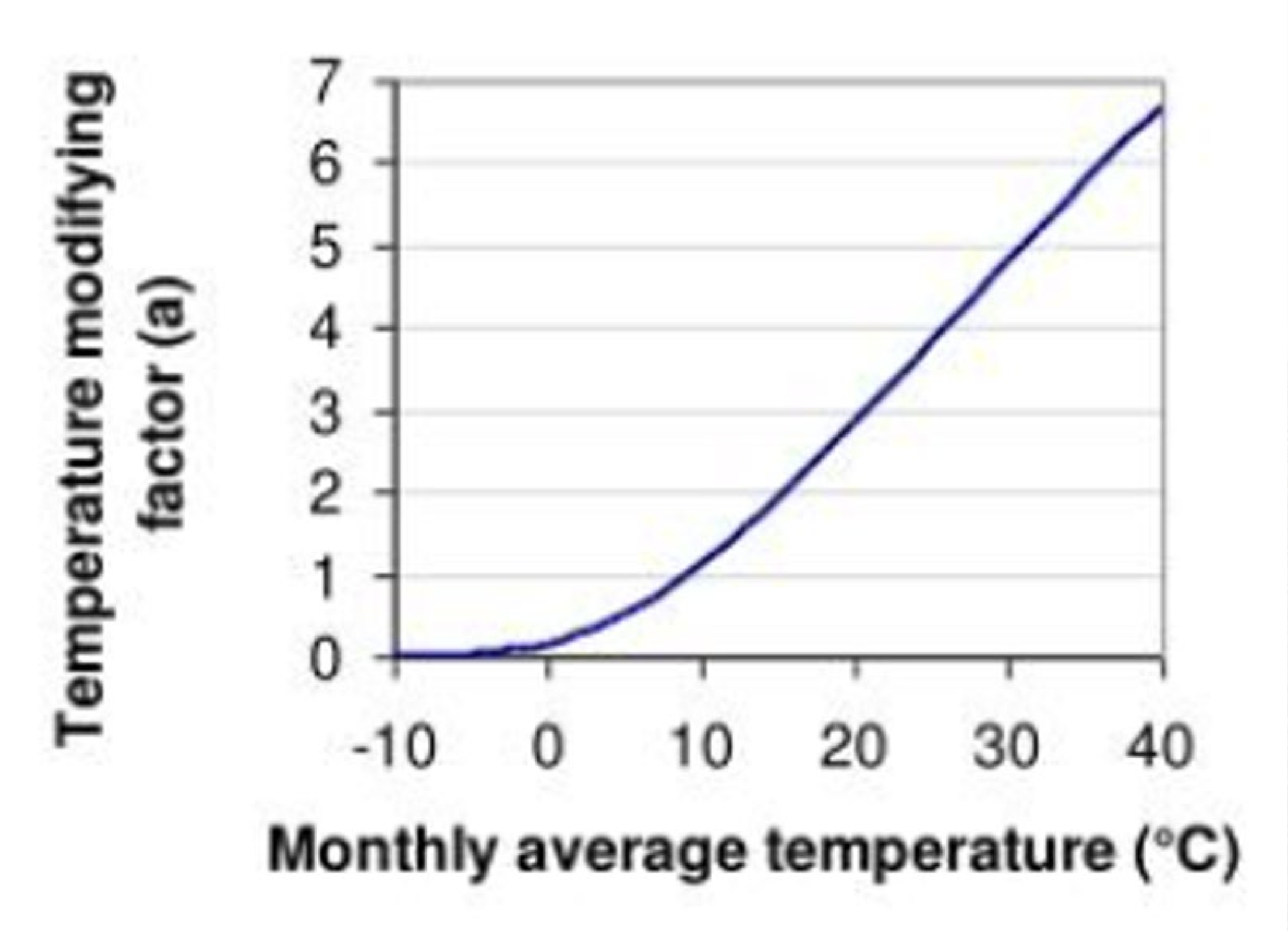
$$Y . e^{-kt} \rightarrow Y . e^{-k.\, a.b.c.\, t}$$

a= temperature factor

b= soil moisture factor

c= soil cover factor

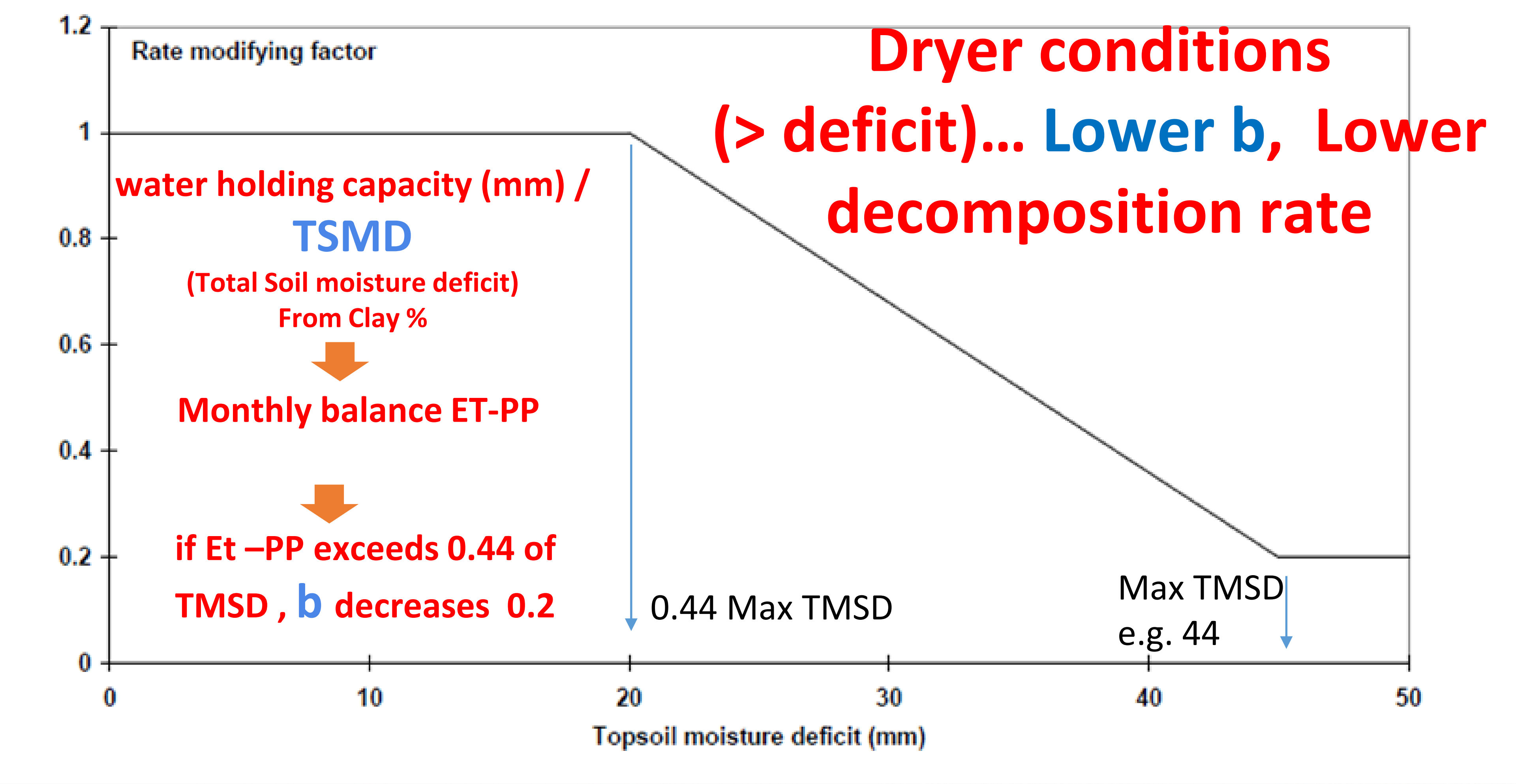
Temperature factor (a)



> Temperature,
> decomposition rate

From: CSIRO: 2008

Soil moisture factor (b)

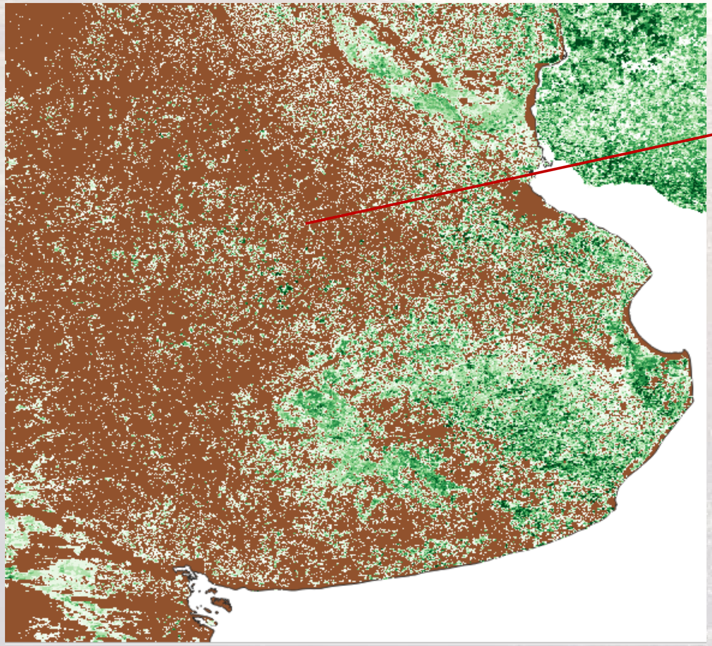


for all

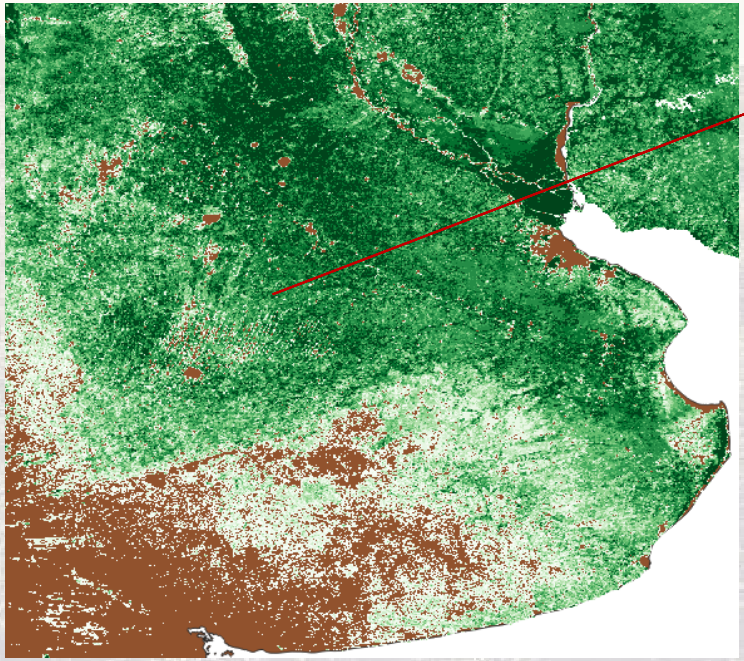
Soil/vegetation cover factor (c)

If soil is vegetated	c=0.6
If soil is bare	c=1.0

If Vegetated, Lower "c" Lower decomposition rate

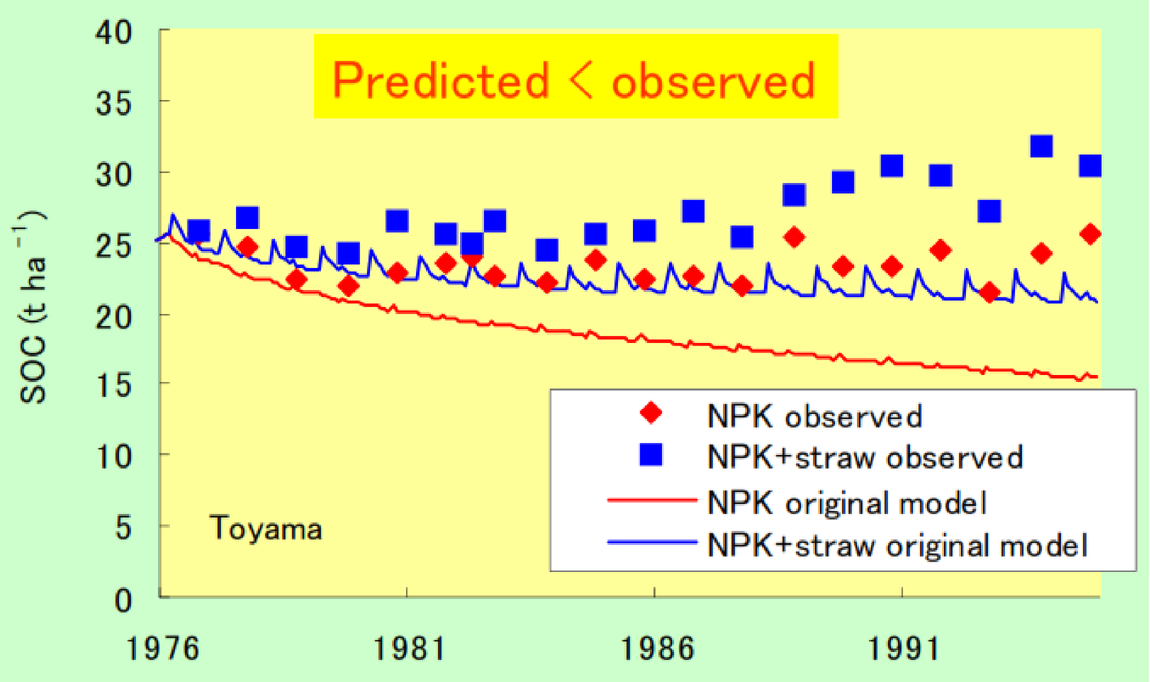


July
No crops
Bare;
c=1.0



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

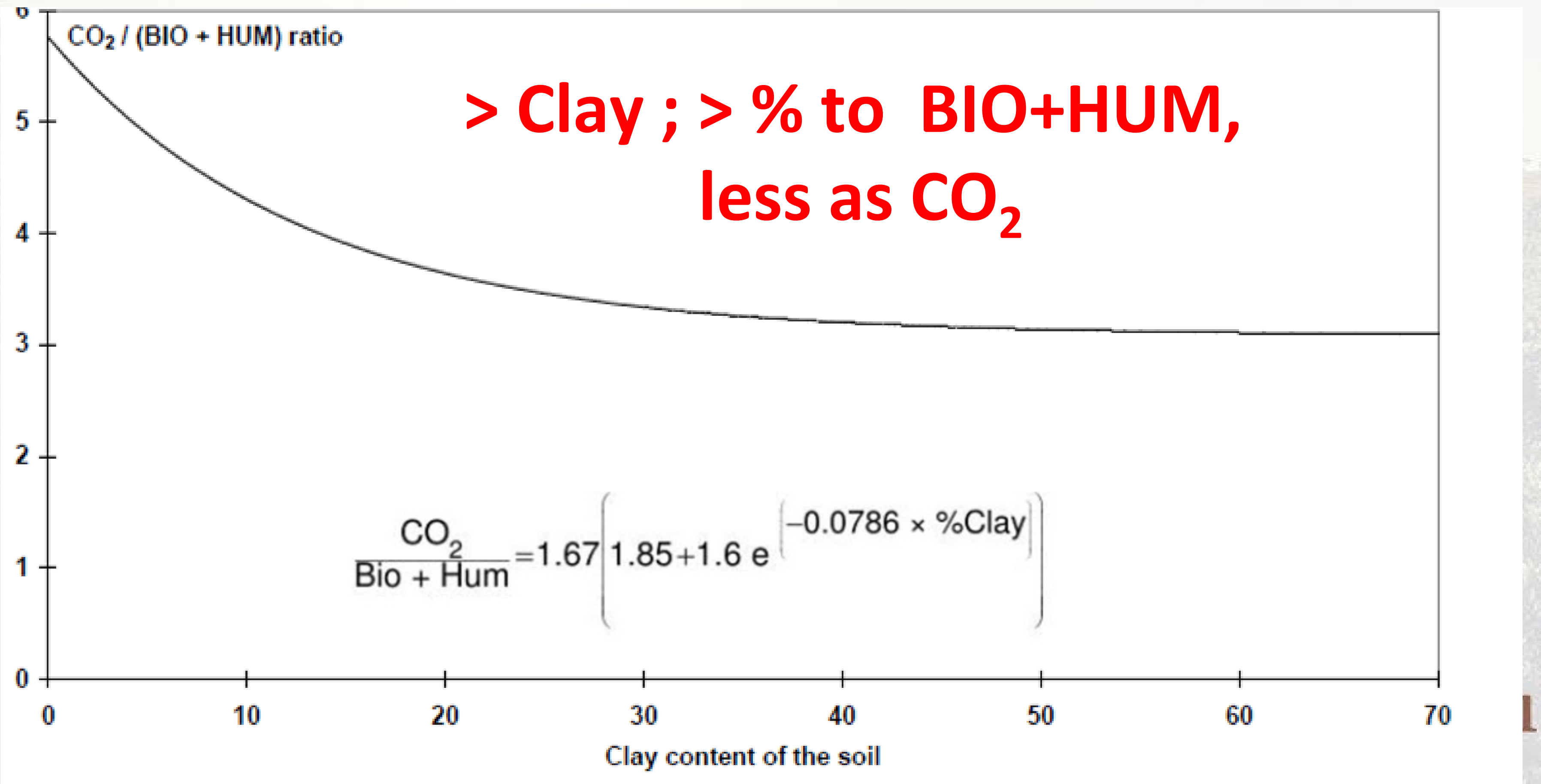
0.6 x k months no flooded rice
0.2 x k with flooded Rice

Paddy rice modifying factor GSOCseq= 0.4 x k

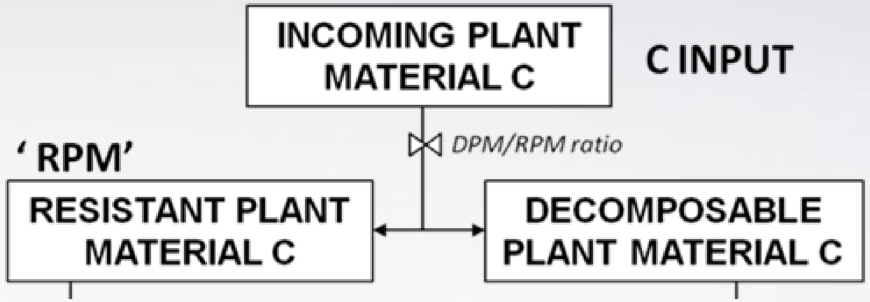
Soil texture

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
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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

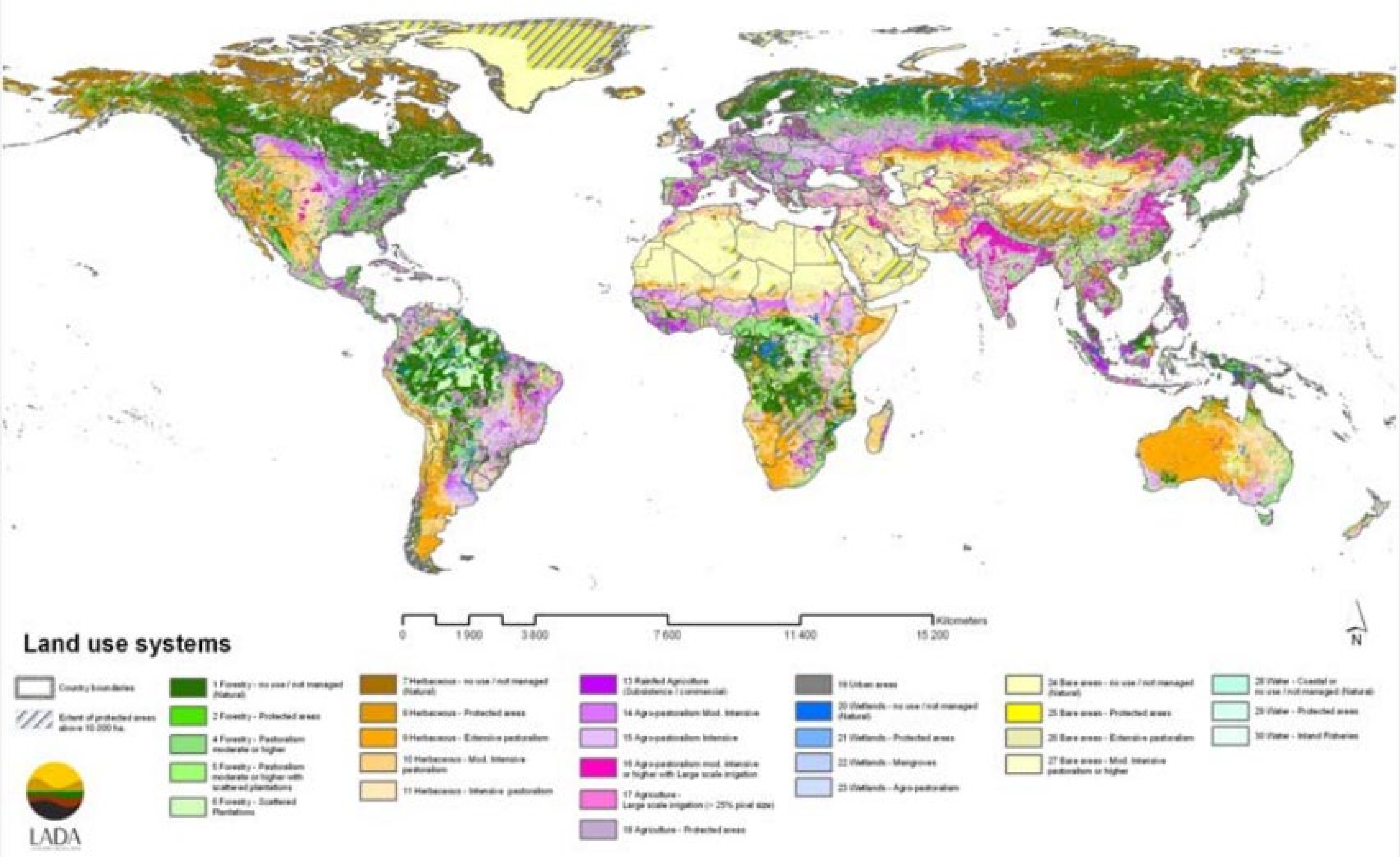
- Each country can improve and modify the tool, develop their own tool (using Roth C to generate the standard products in a first stage)

- **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**

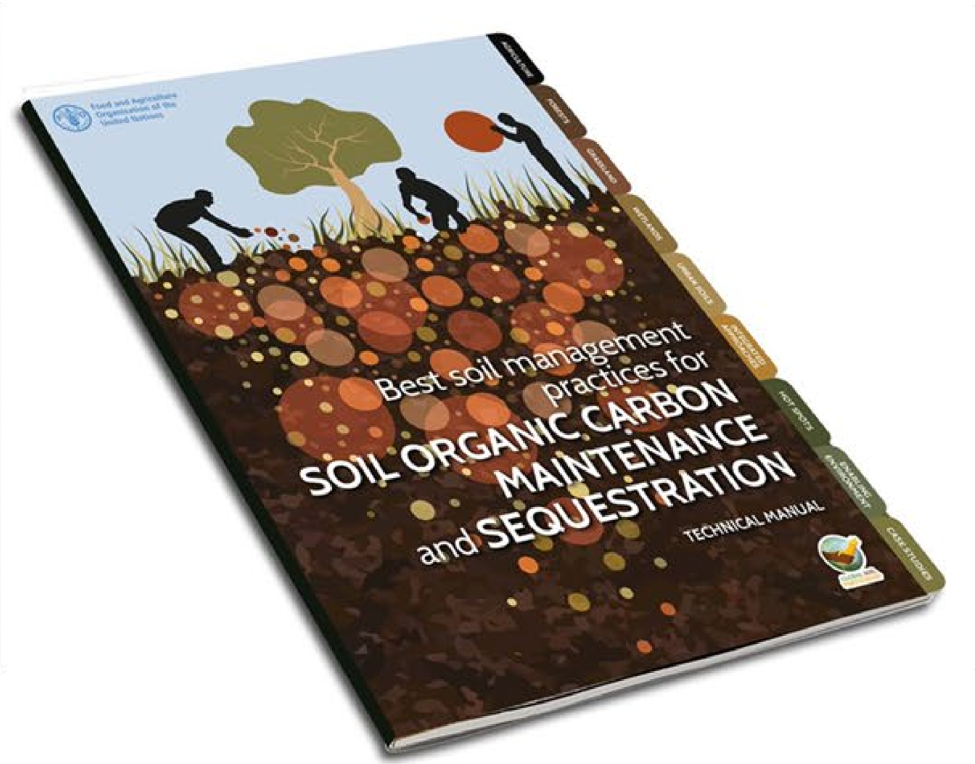
Conservative ranges...may be high for other systems

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

nagement for all

SSM practices

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

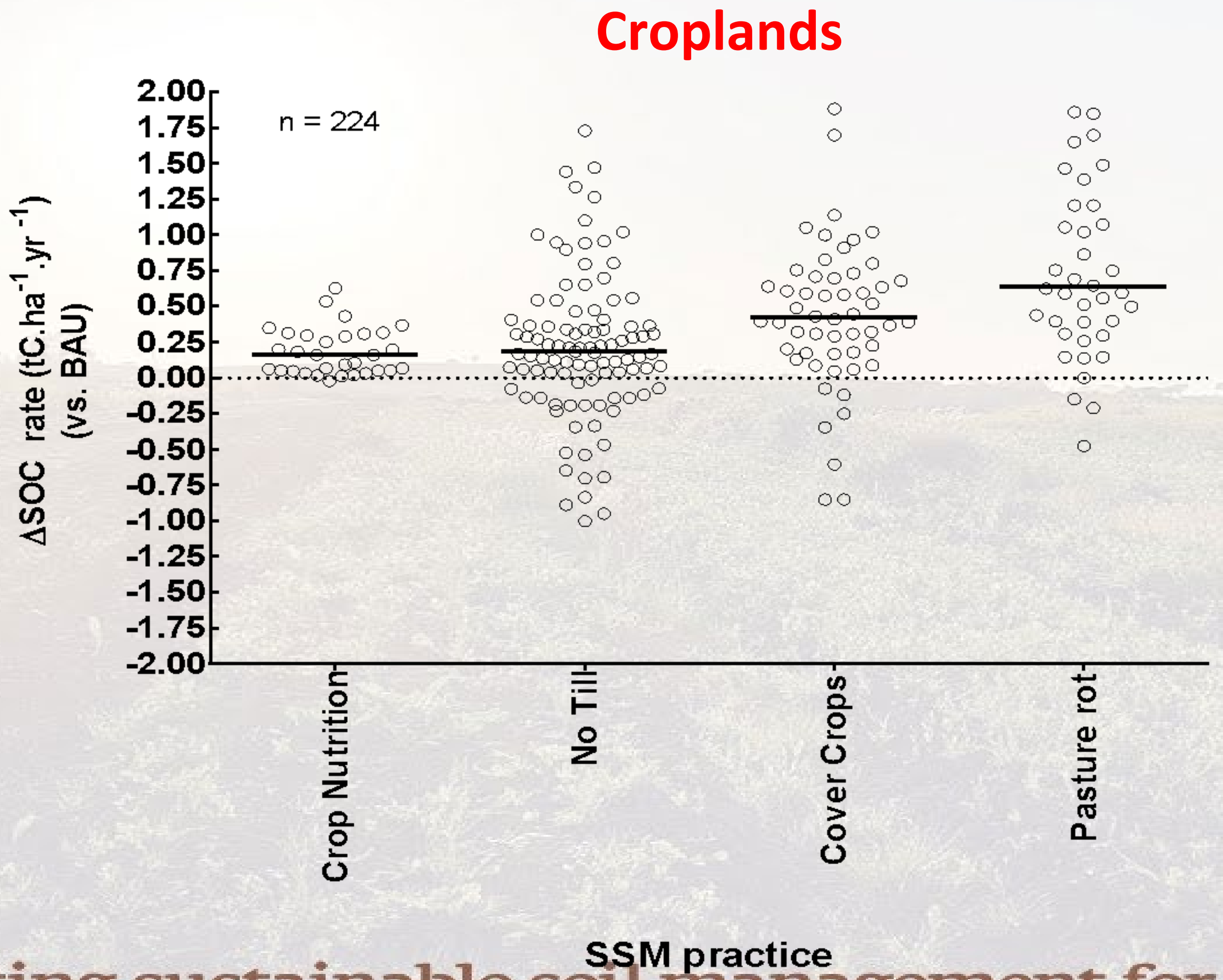


..and many other practices around the world…

Local adjustment of scenarios and % increase in C inputs

E.g.

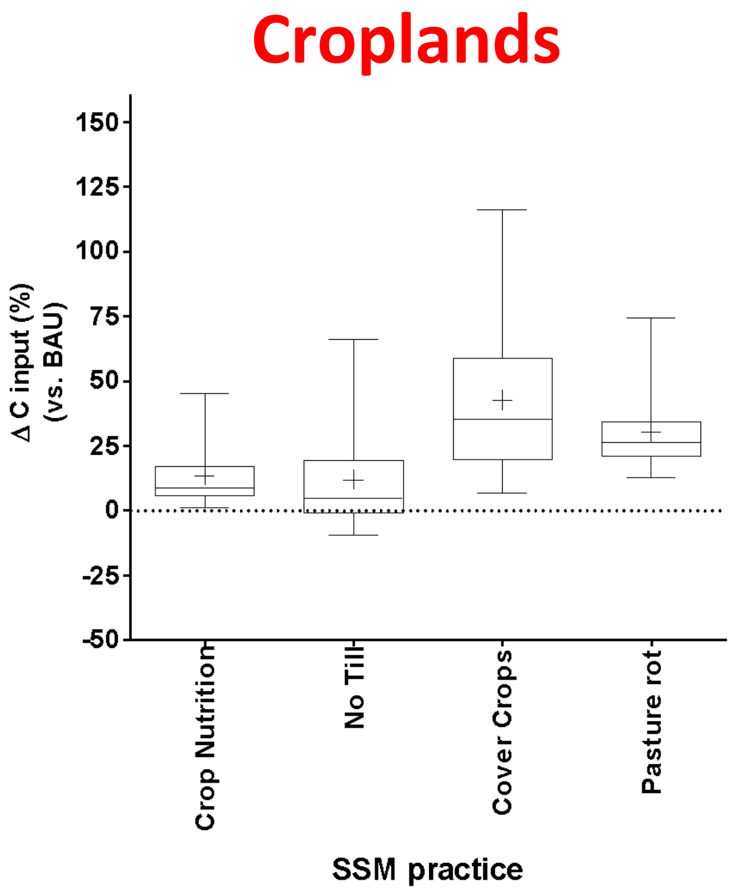
Ad hoc Meta-analysis from local studies

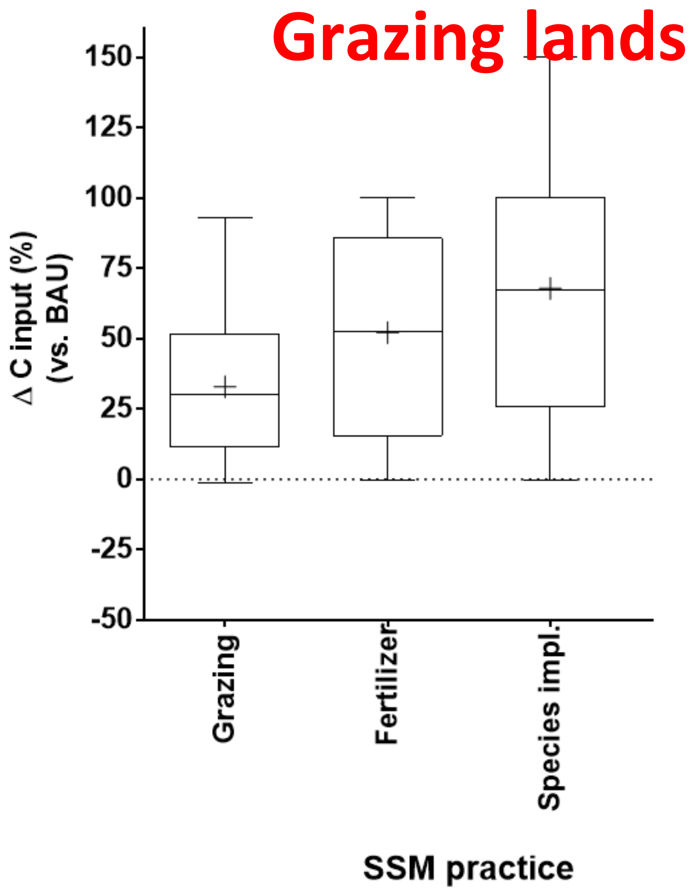


Local adjustment of scenarions and % increase in C inputs

E.g.

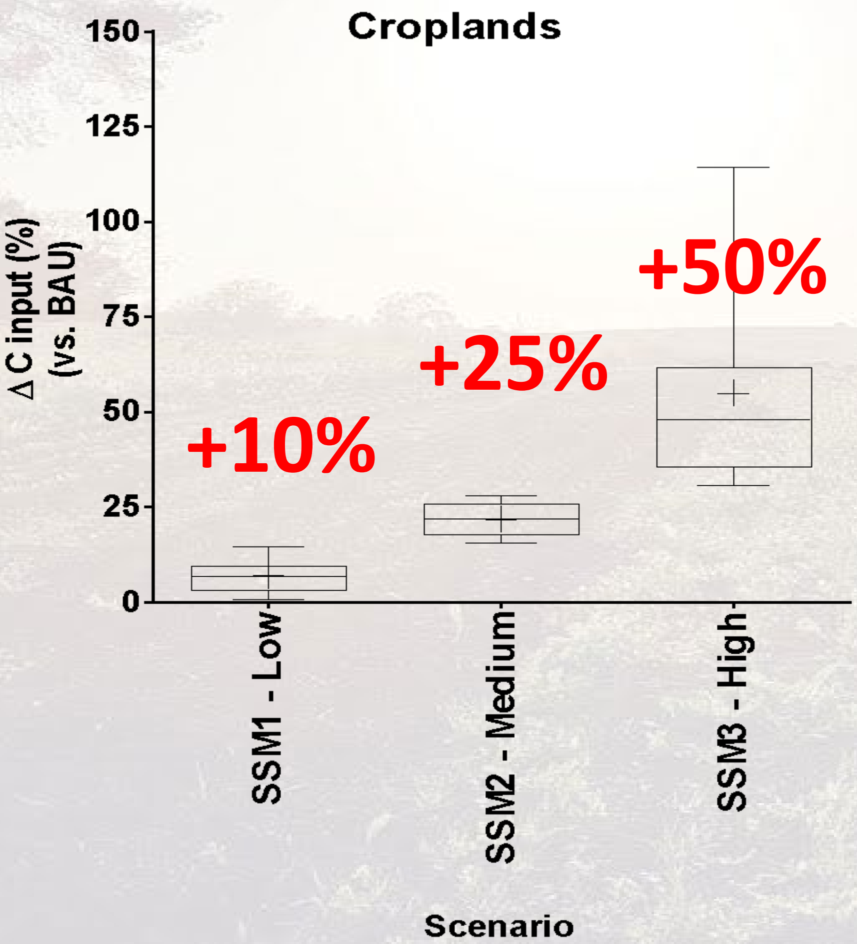
Ad hoc Meta-analysis from local studies

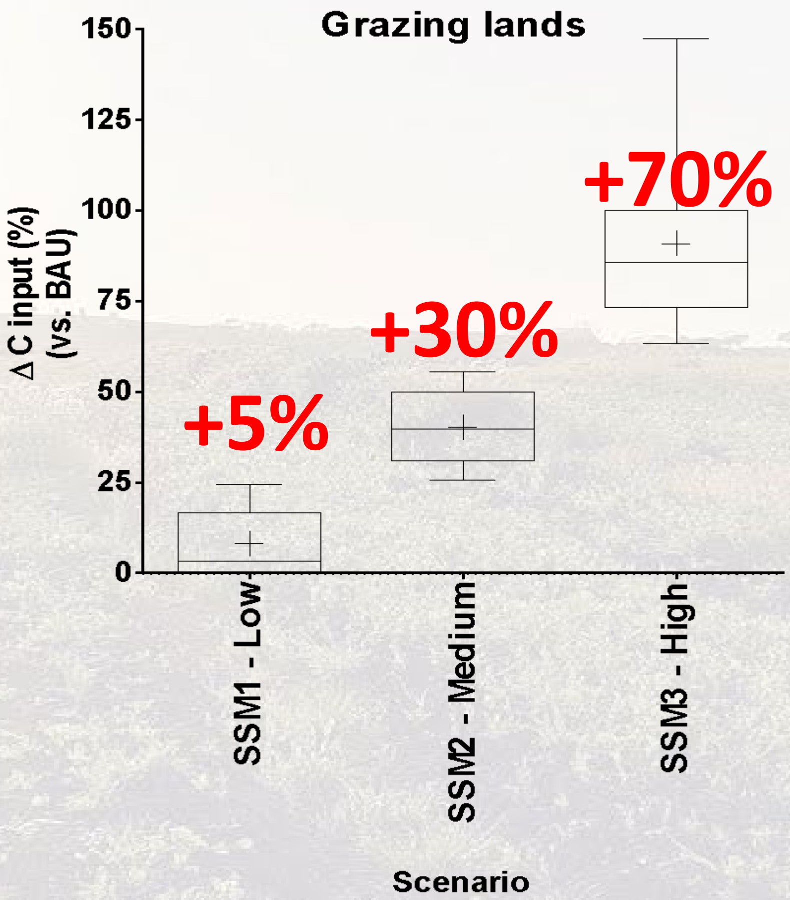




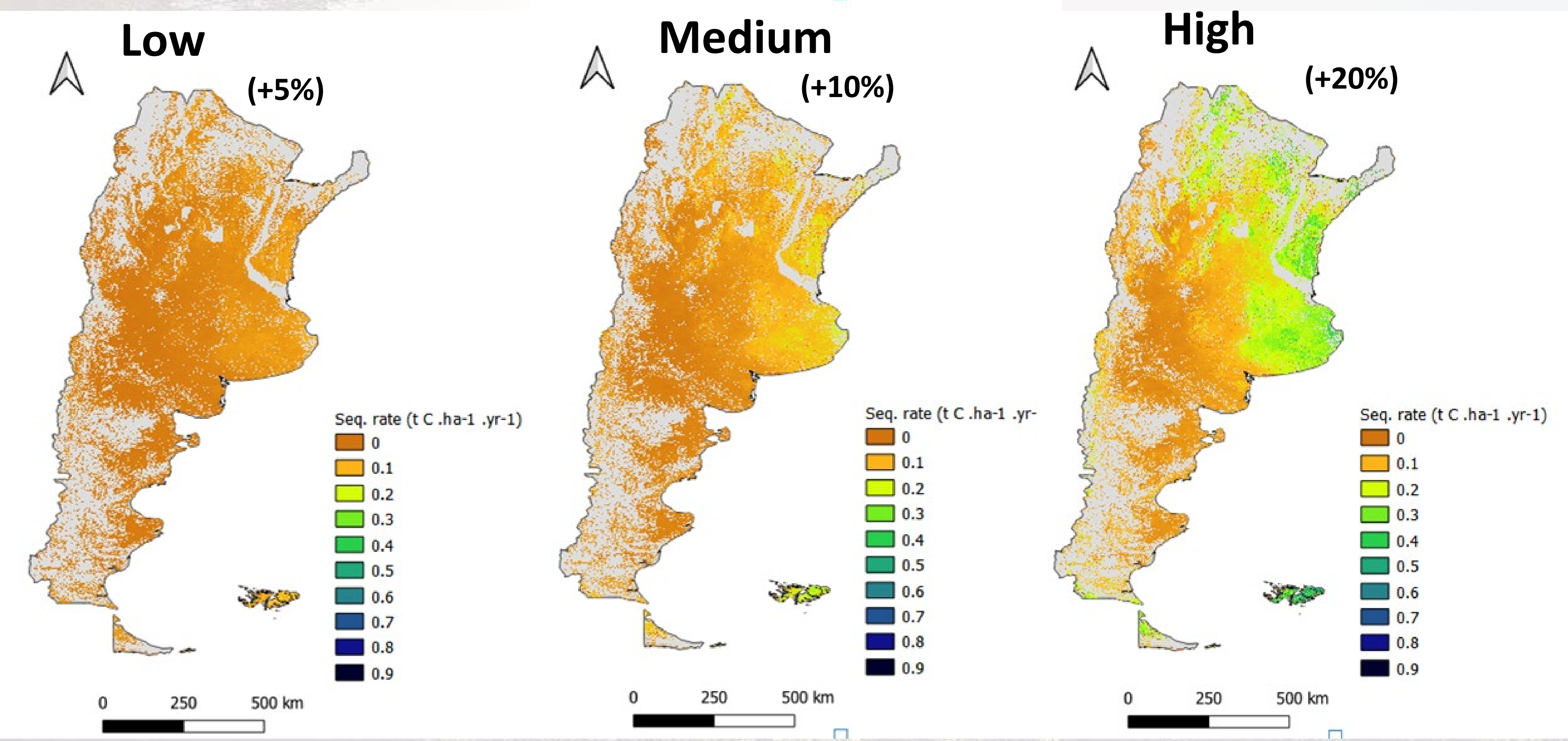
Local adjustment of scenarions and % increase in C inputs

E.g.





Standard Products

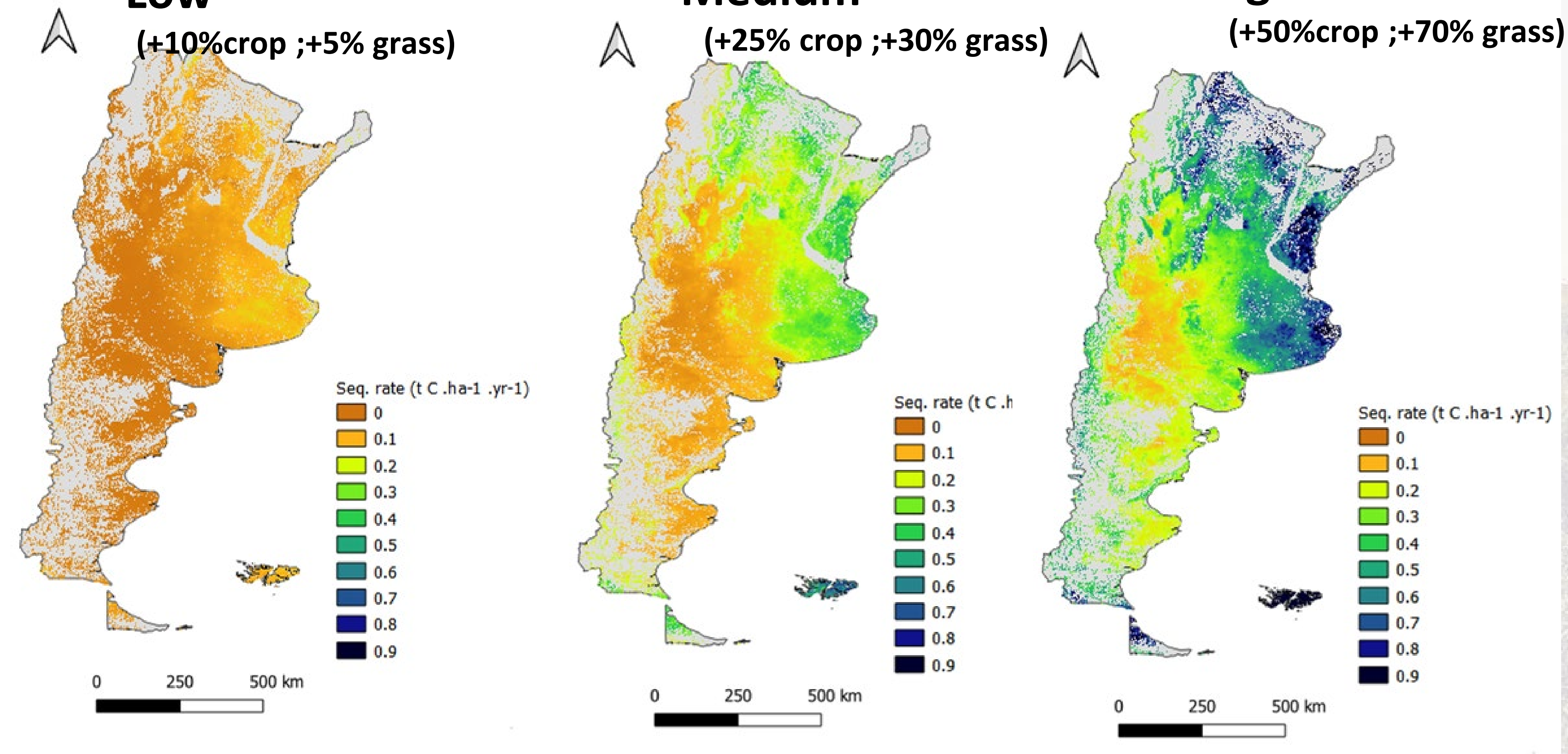


Non-Standard Products
Using modified coefficients

Low
(+10%crop ;+5% grass)

Medium
(+25% crop ;+30% grass)

High
(+50%crop ;+70% grass)



To simulate SOC changes for each 1km x 1km pixel:

Based on Smith et al 2006; 2008; Gottschalk et al 2012

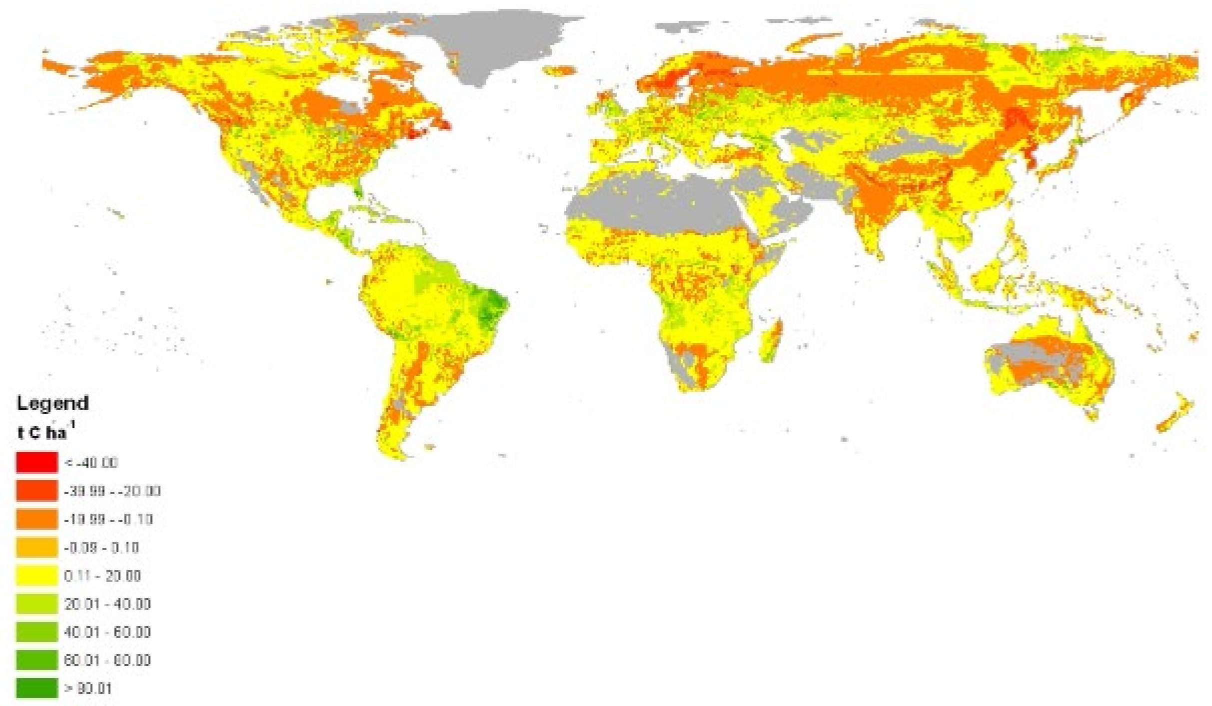
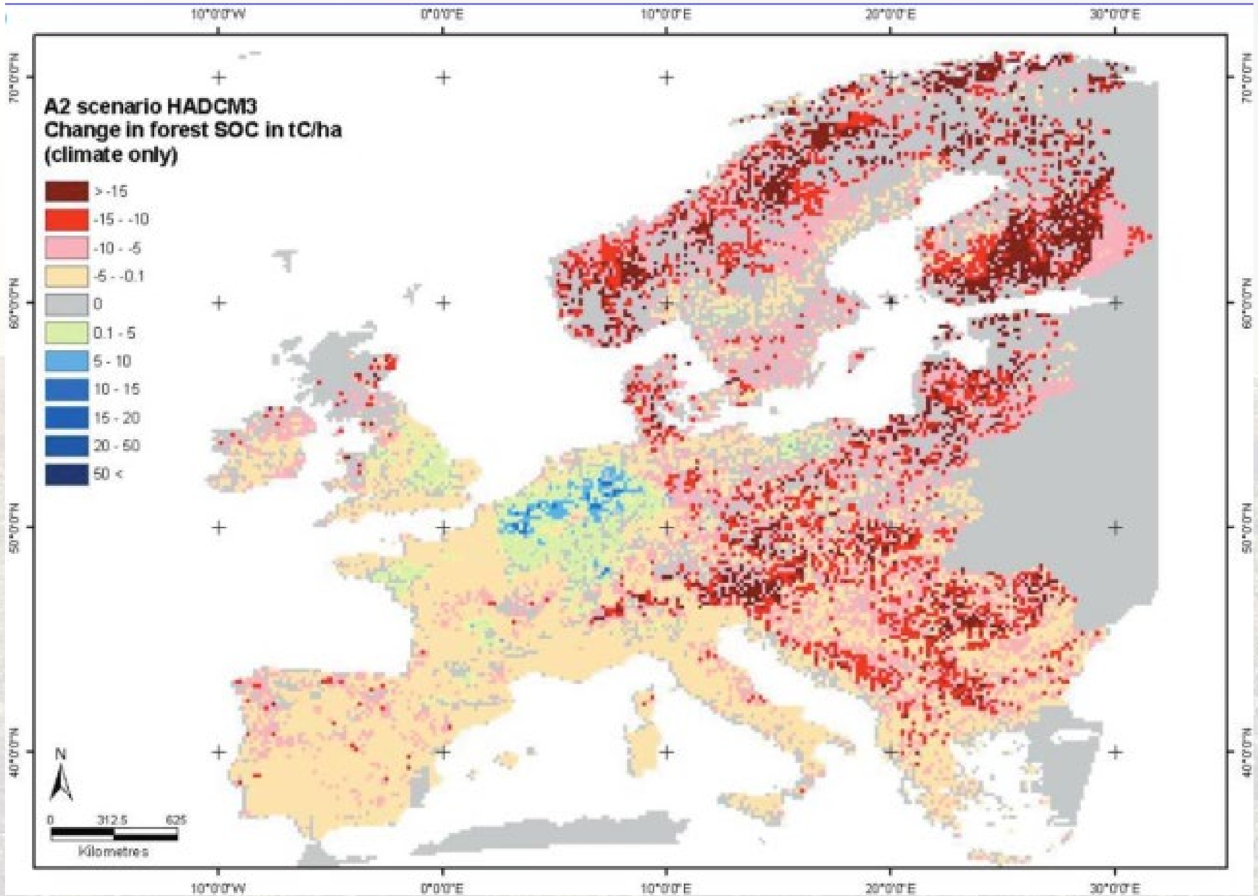


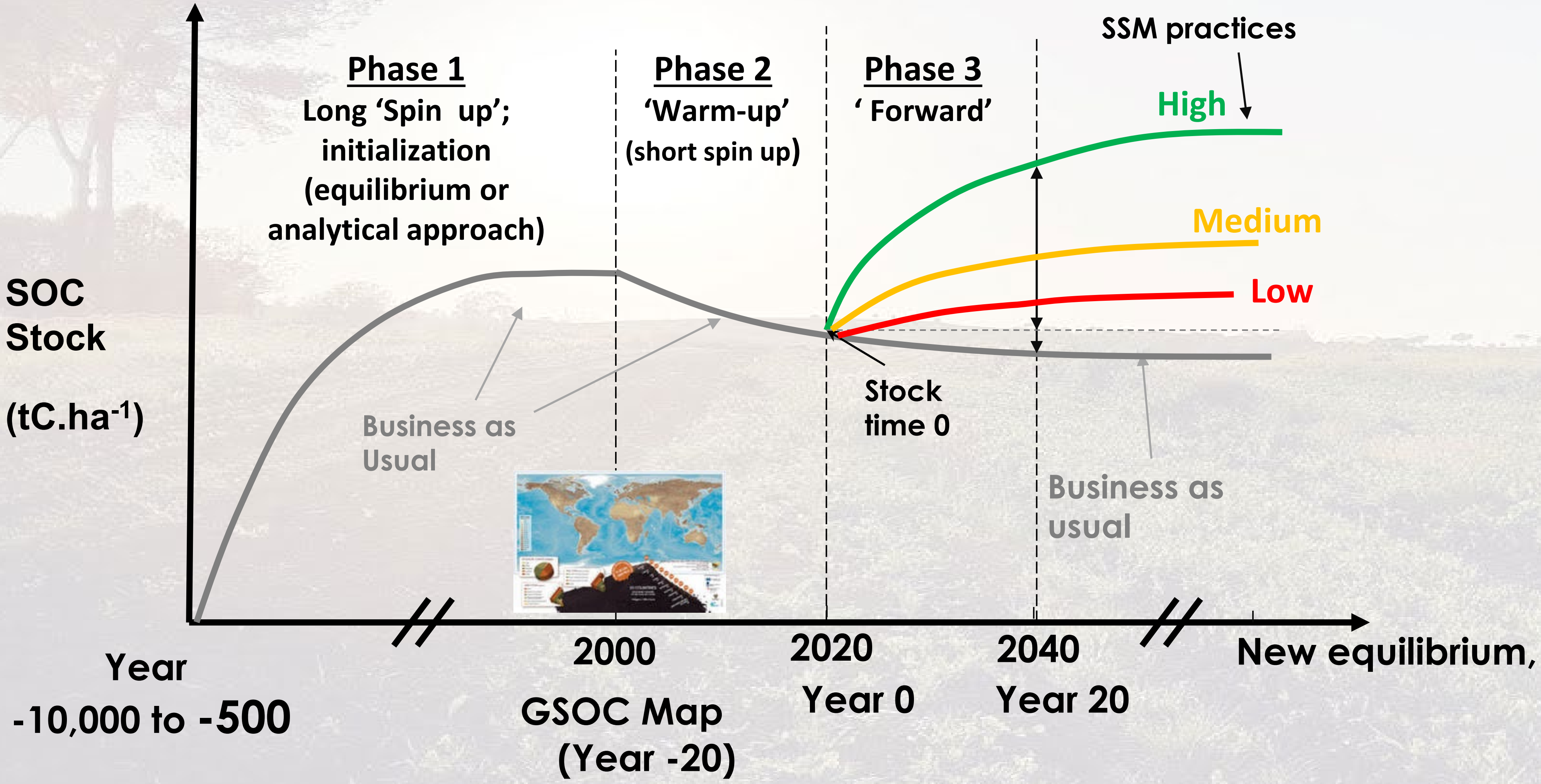
Fig. 7. Average trend in SOC concentration of all 10 scenarios from 1971 to 2100.

Gottschalk et al 2012



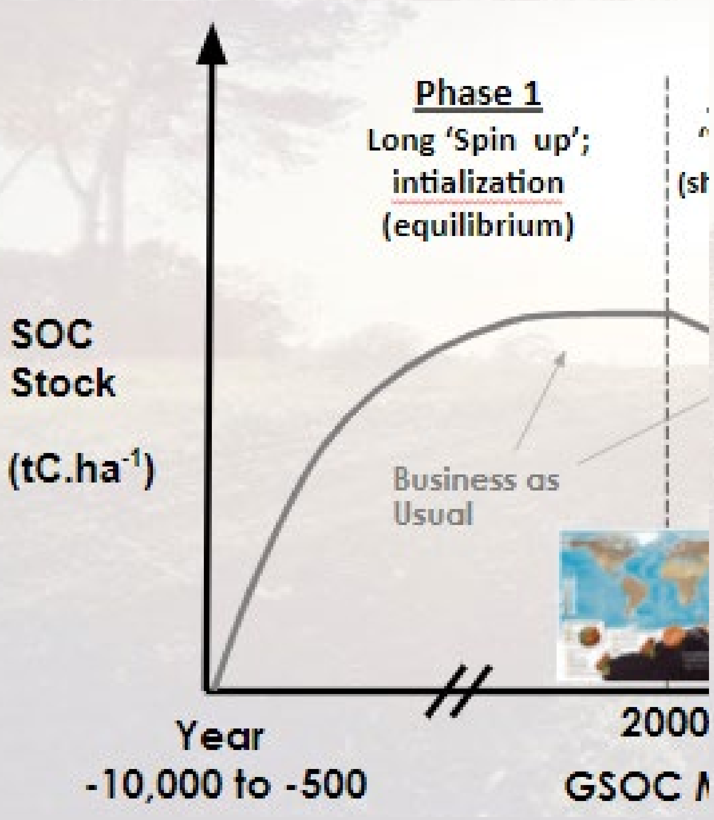
Smith et al 2006

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)**

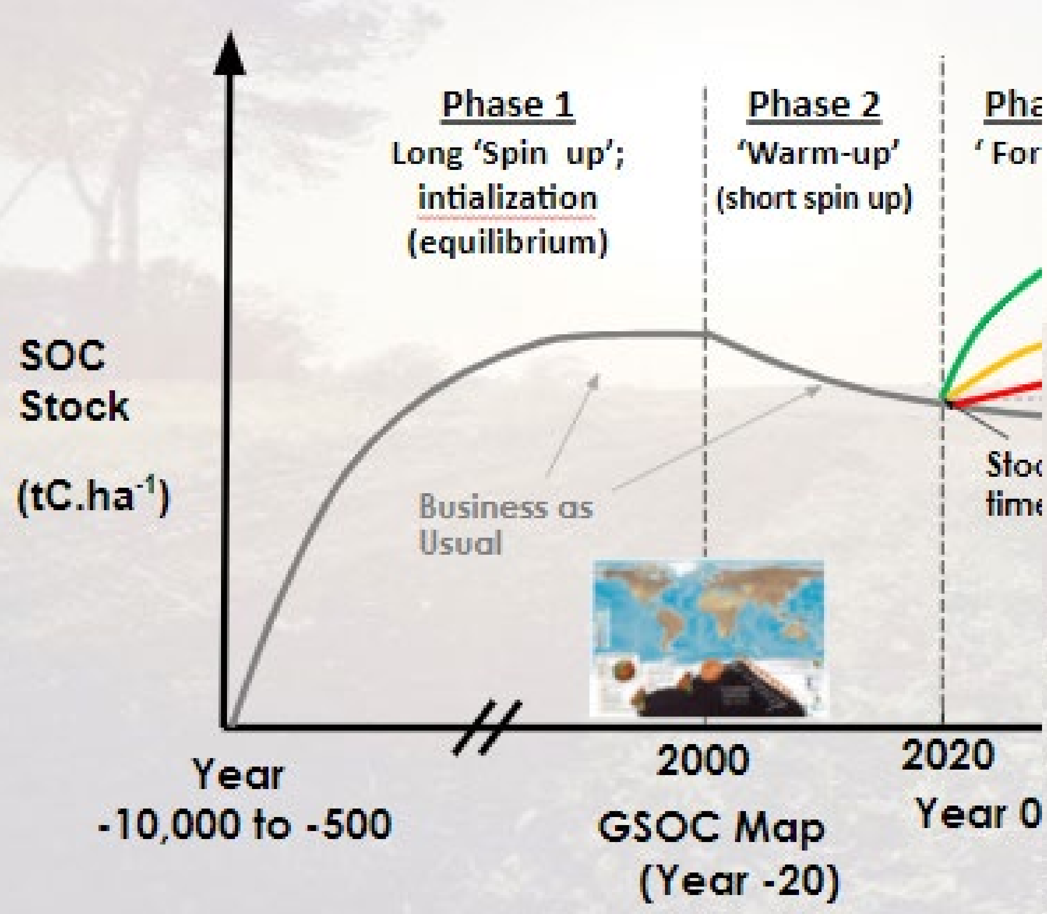
  Ceq = C inputs under business as usual/baseline

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)
- Other preferred NPP sources/models can be used

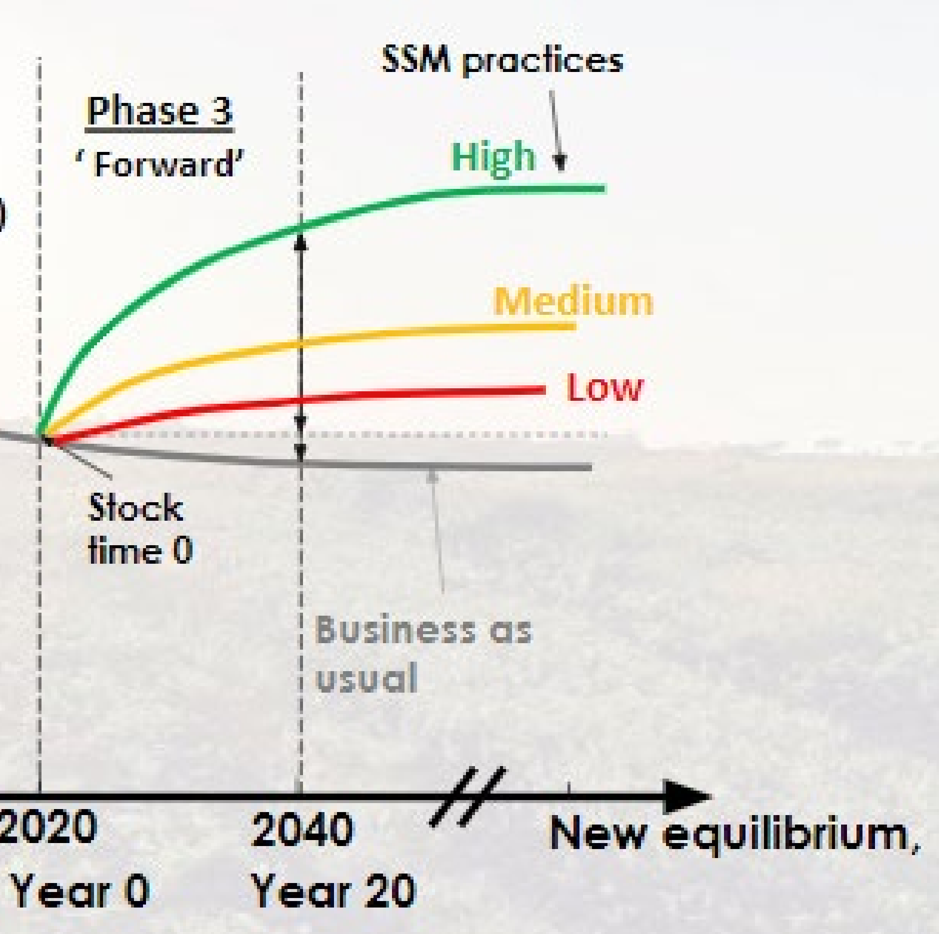
NPP can be adjusted for Land Use changes (Schulze et al 2010)

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

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

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

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

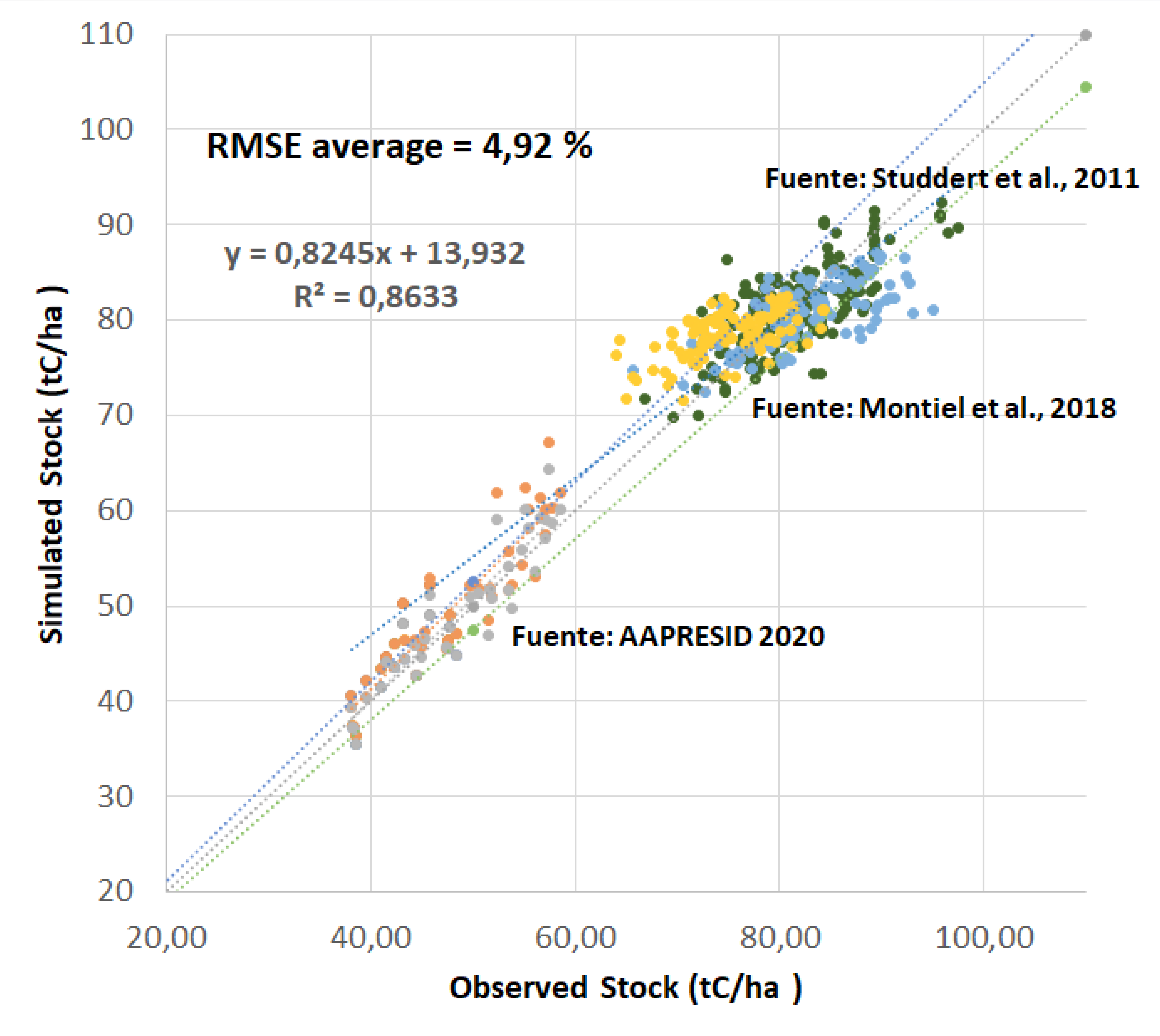
- Validate changes that did not happen yet?
- Complex methods (e.g. Montecarlo) require multiple simulations (computational time)
- Data availability, uncertainty in input layers

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

1st Step

Model evaluation with pre-existent data

Meta-anlaysis local studies



2nd Step

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

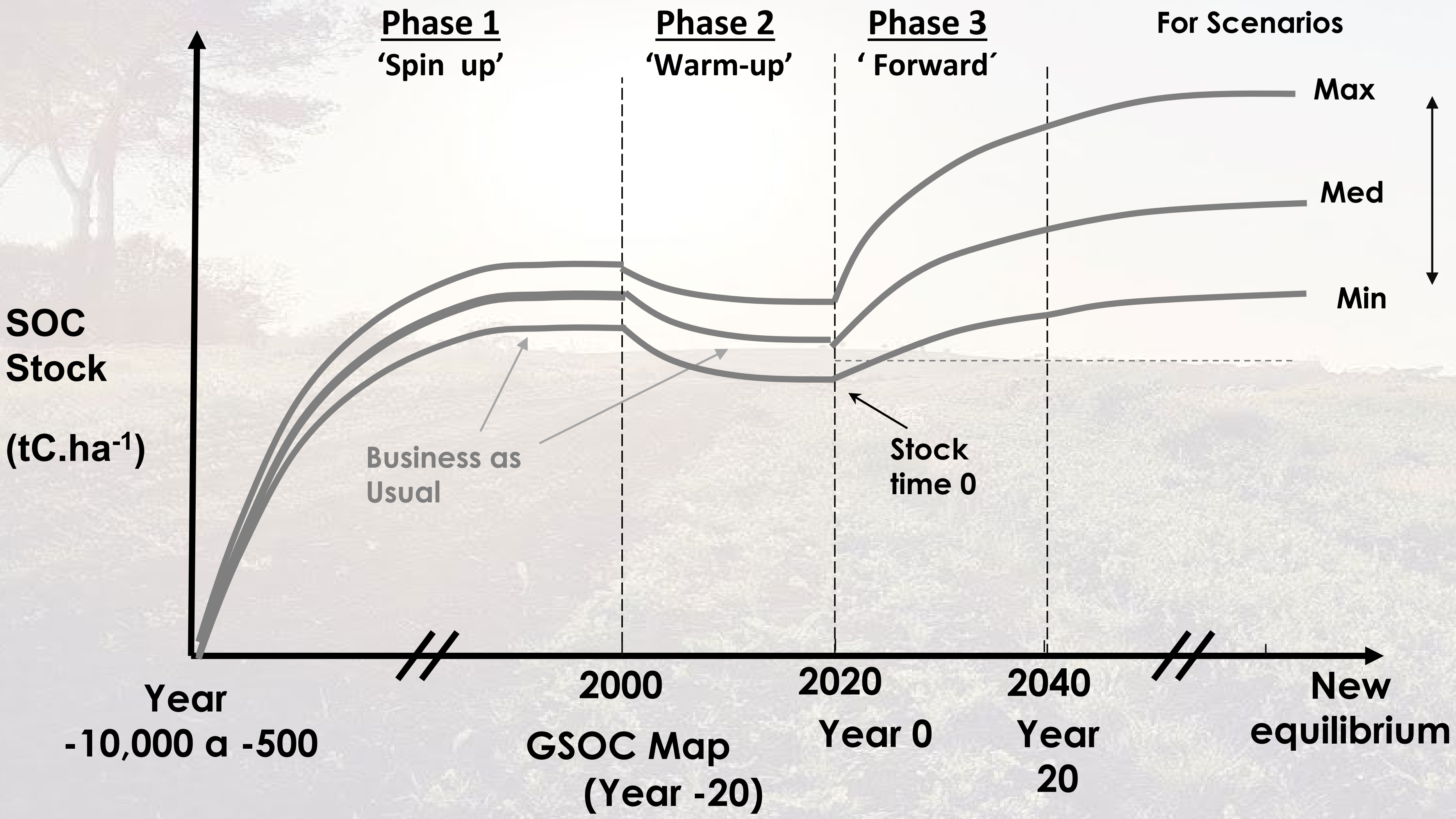
SOCav = the average of the estimated SOC at the end of the simulation (t $C.ha^{-1}$)

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



promoting sustainable soil management for all

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

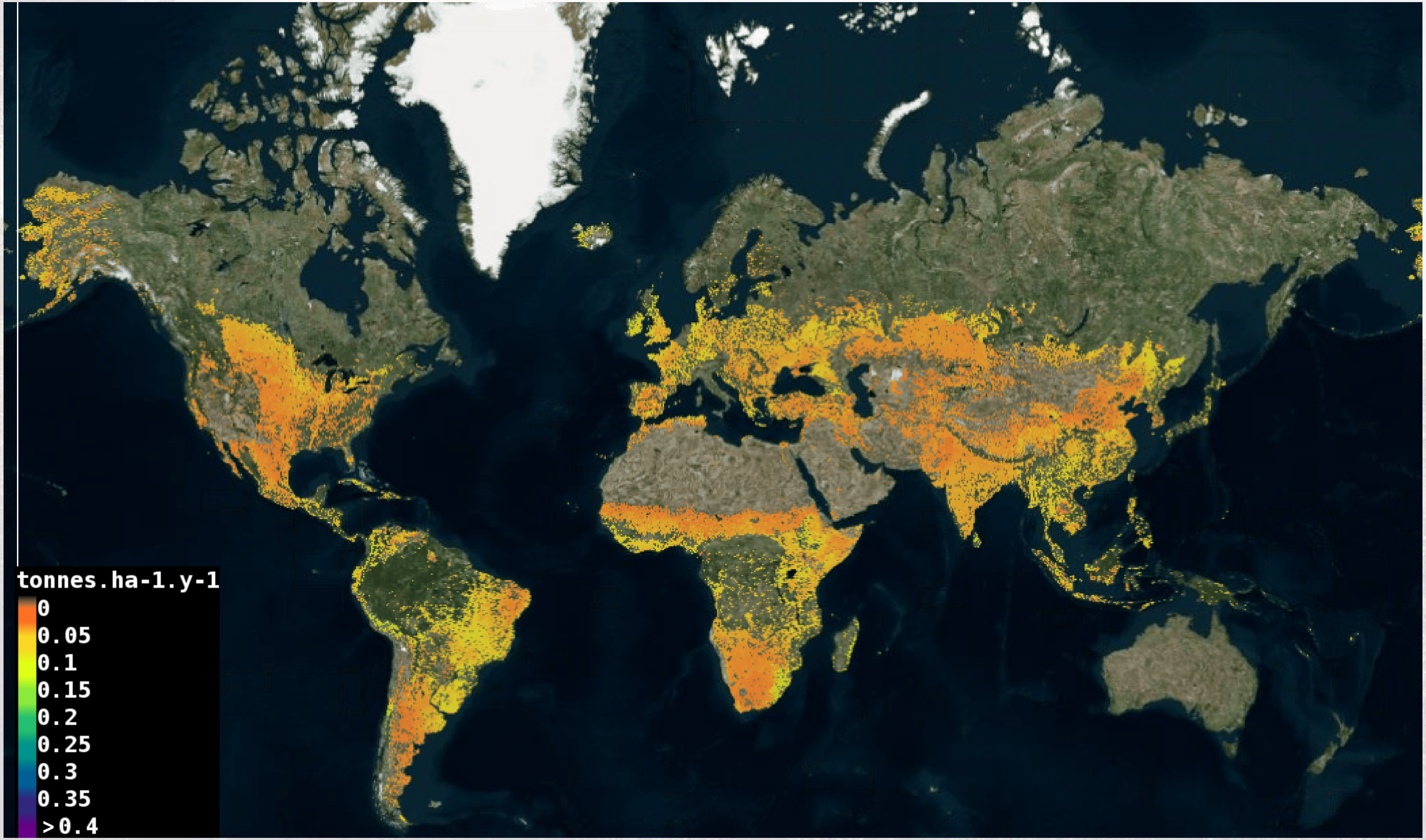
http://54.229.242.119/GloSIS/

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

SSM1 >> SSM3

GSOCseq v1.1

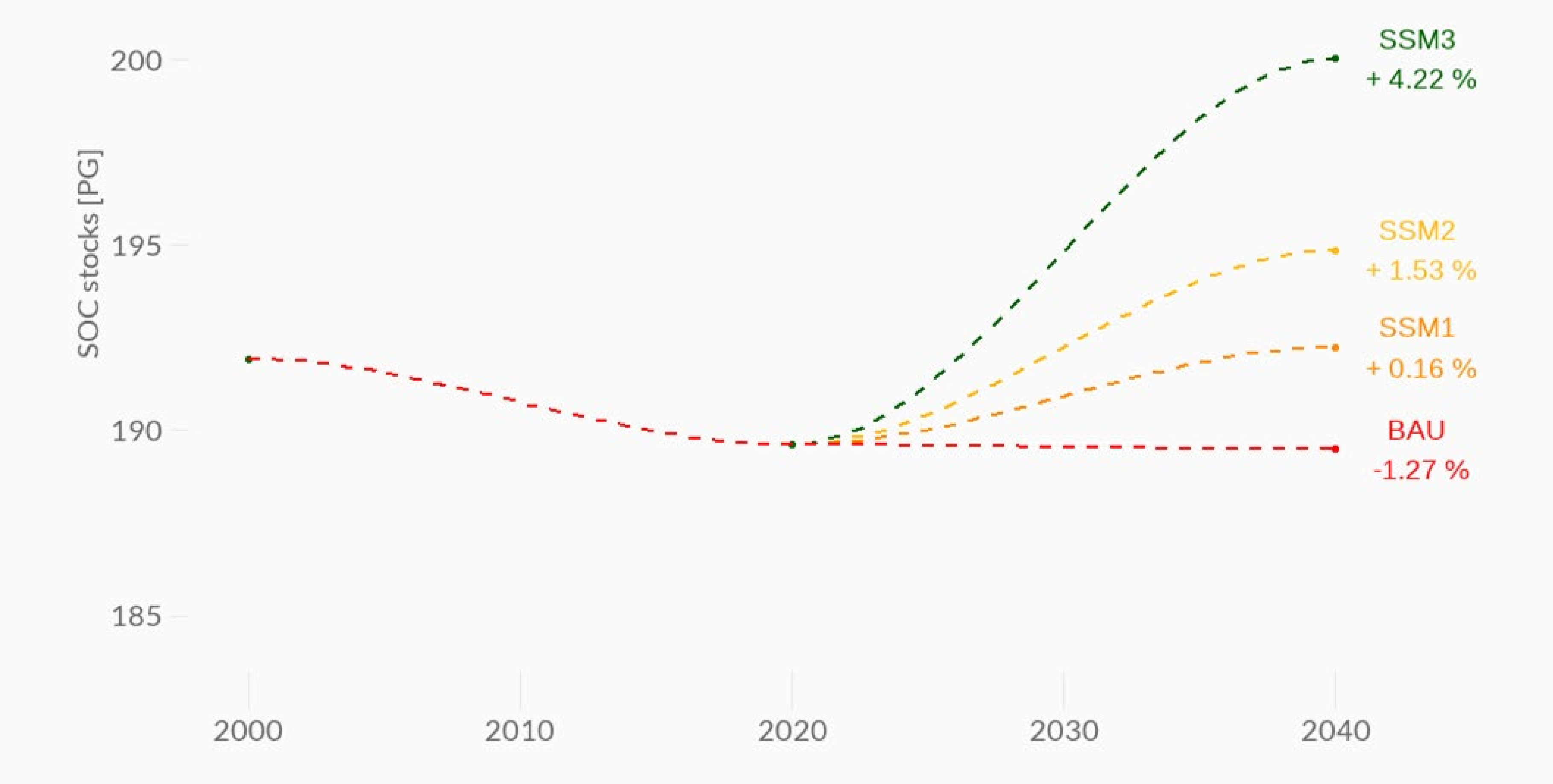
- SOC sequestration (tC/ha/yr) SSM 1-3
- Agricultural lands (croplands + grazing lands)
- 20-year period
- Depth: 0-30 cm
- 1 x 1 km resolution



GSOCseq v1.0.0 Uncertainties (%)

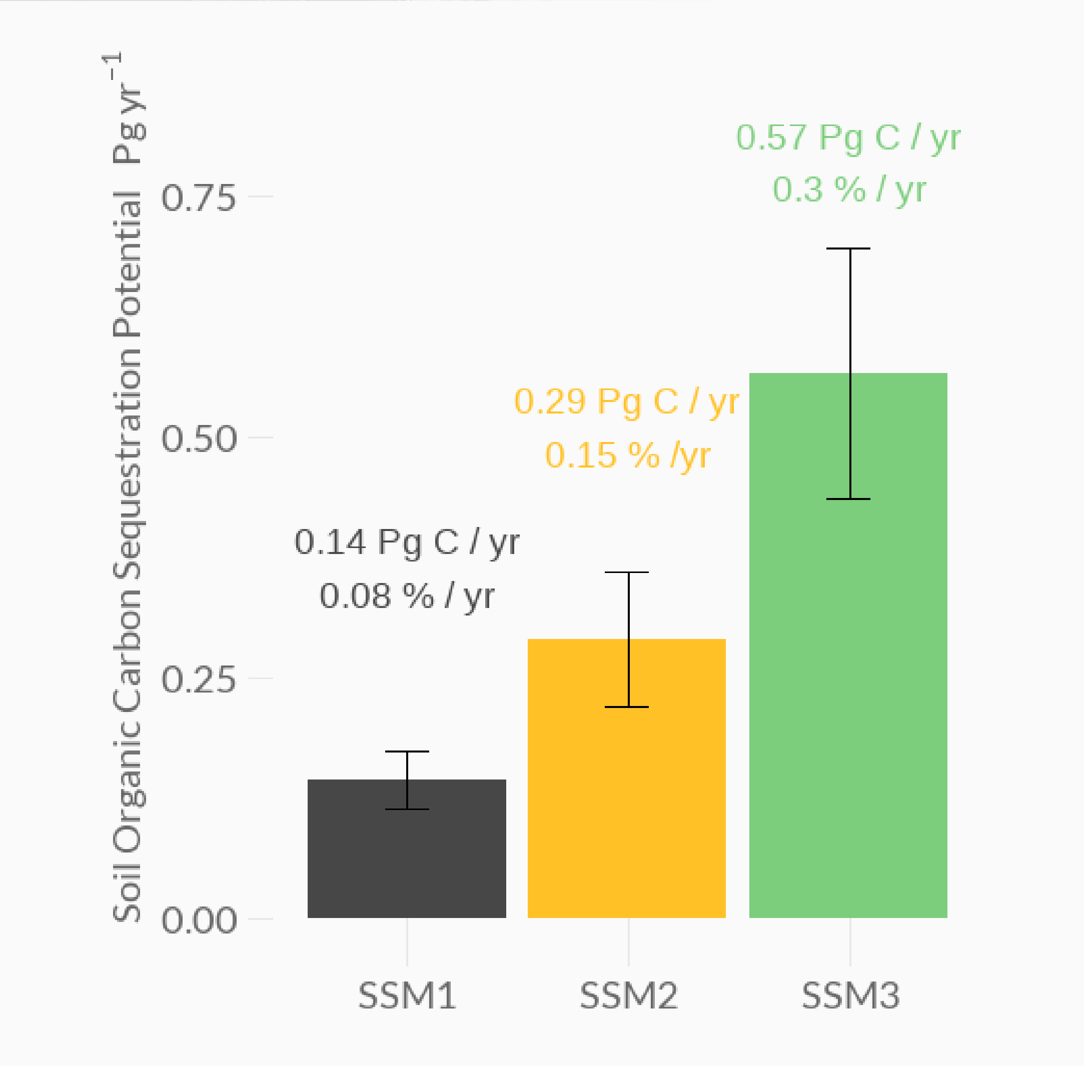
First results - Global SOC stocks*

*Excluding blank countries (GSOCseq v1.1)



First results - Annual SOC sequestration *

*Excluding blank countries

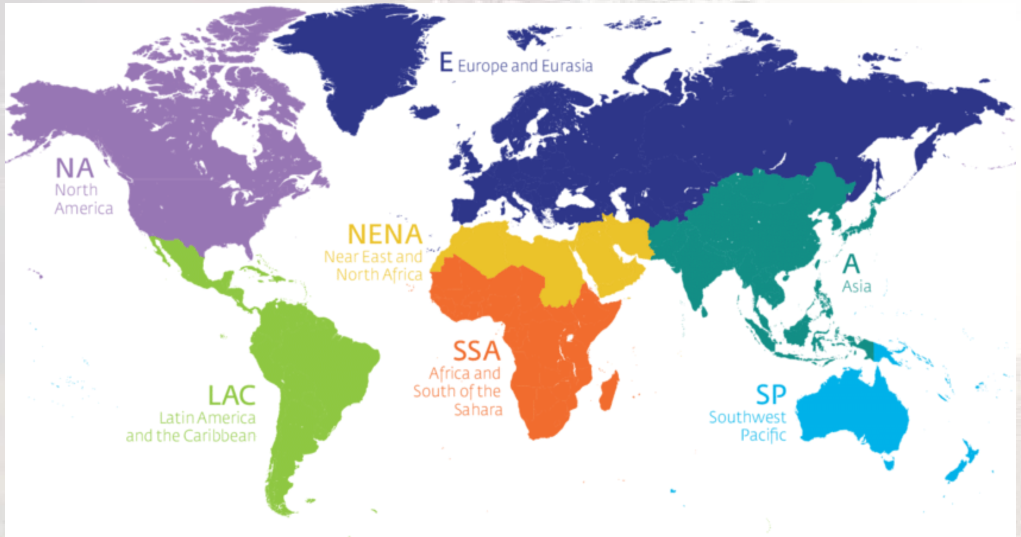


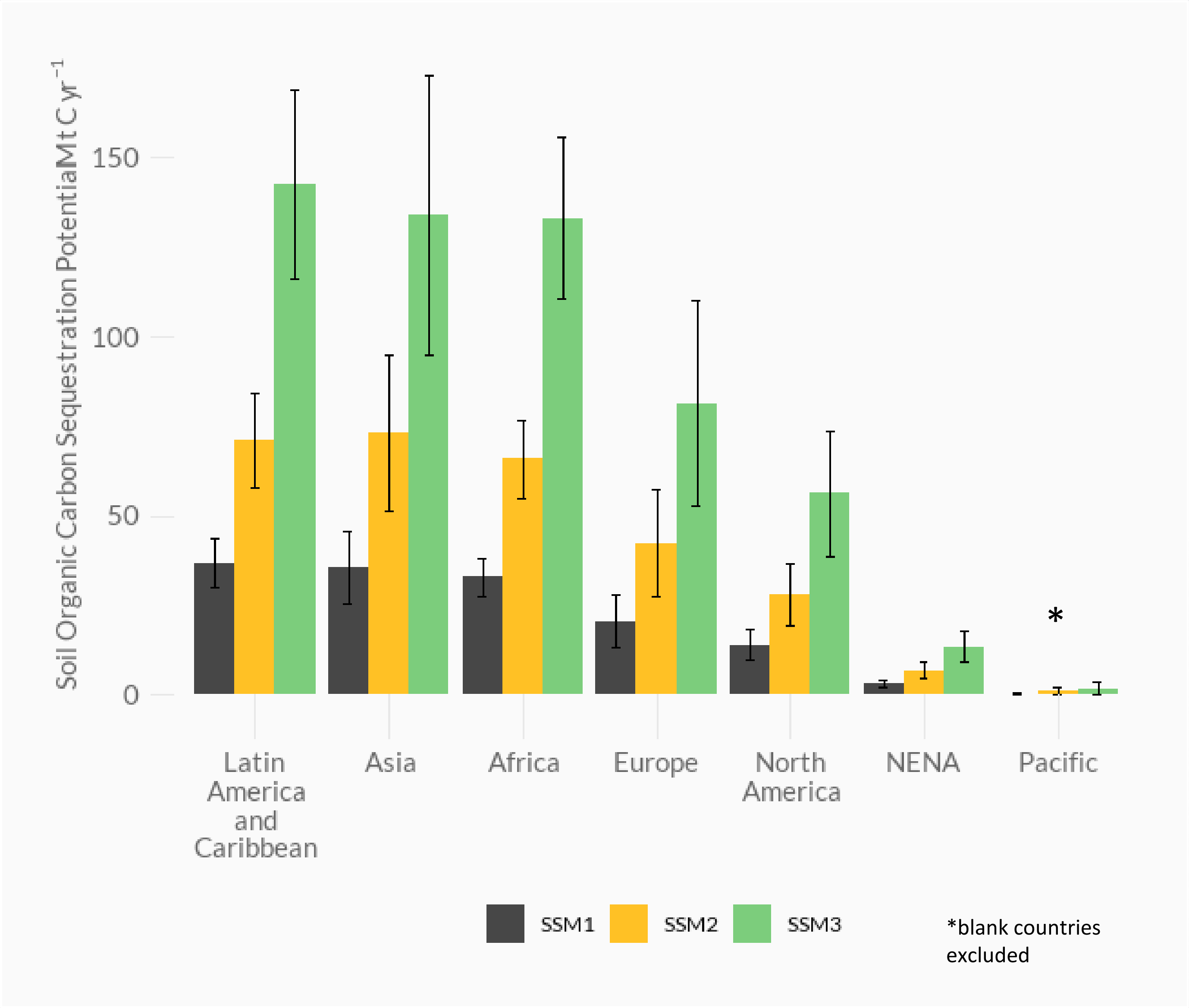
Previous estimates

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?

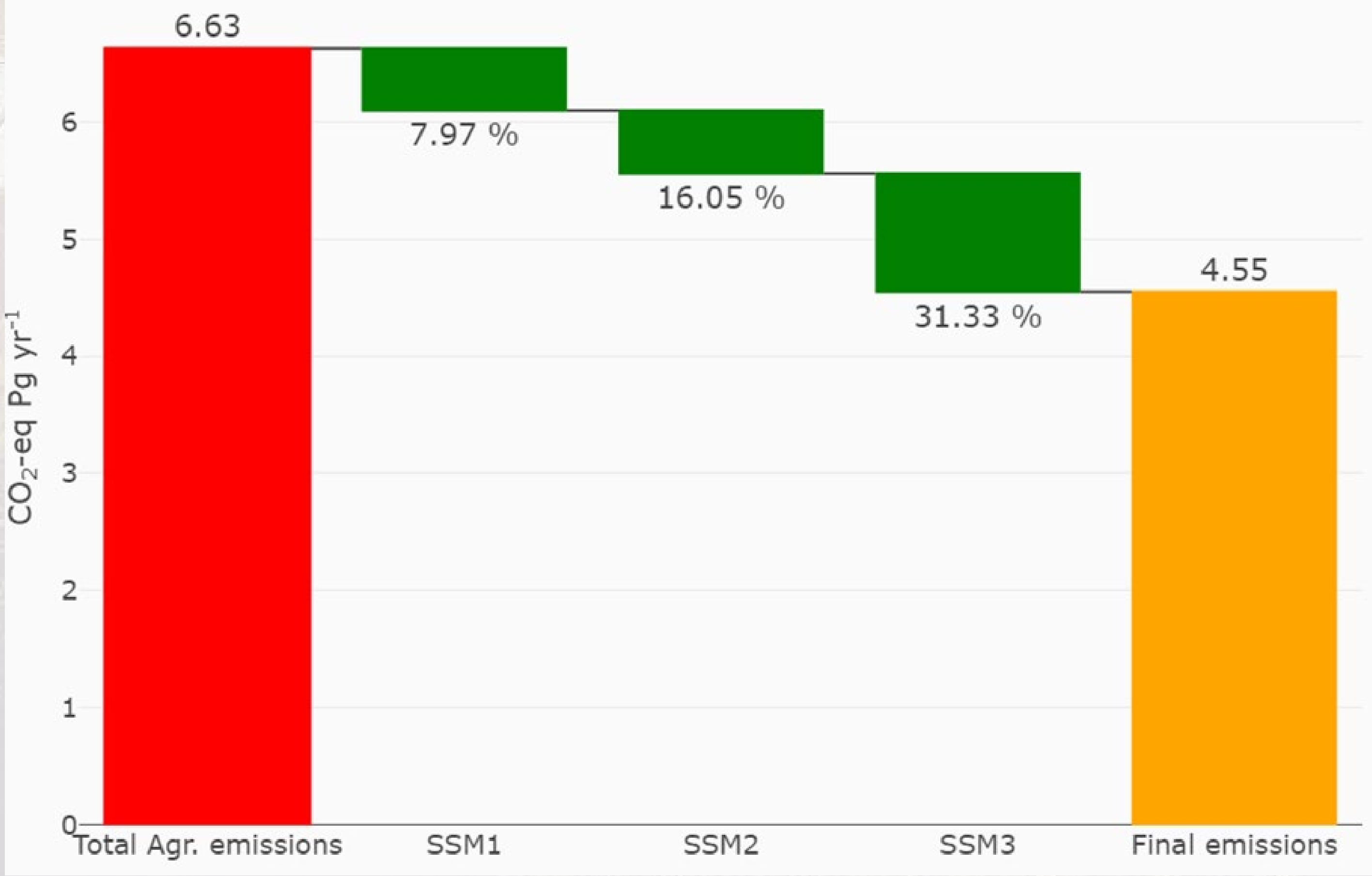




Potential uses - Mitigation Potential*

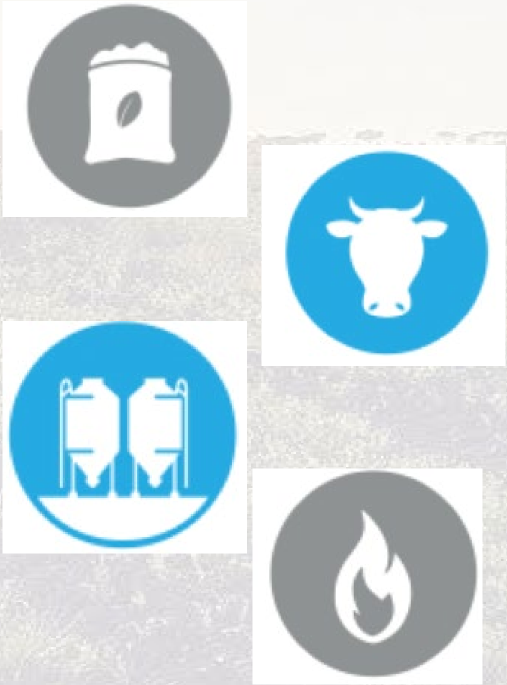
*Excluding blank countries

Agricultural soils play an important role in mitigating GHG emissions: yearly agricultural global emissions could be cut by 31 %

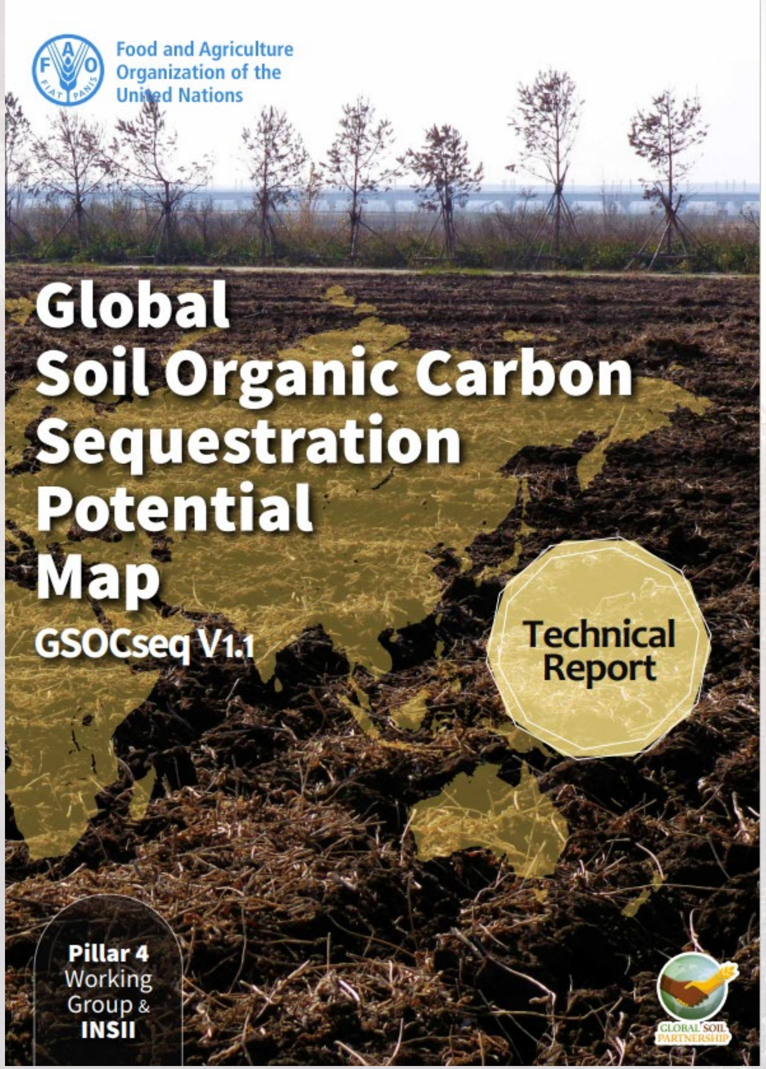


*Total Agricultural Emissions from FAOSTAT (2019)

Also work on other mitigation strategies :



GSOCseq v1.1 Technical Report



- Under review
- To be periodically updated as more national maps are delivered

Useful documentation - Folders

- Technical Specifications and Guidelines (pdf)
- Technical Manual (pdf) (Step by Step)
- Template report (.doc)
- Training Material : SCRIPTS Folders 0 -9 -INPUTS - OUTPUTS
- Workshop presentations (.ppt)
- Useful documentation (RothC Win Manual, Soil R Manual; related publications) (.pdf)

Software requirements

- R software - R Studio
- Qgis 3.x
- Google Earth Engine account

R packages

Protocol application area	R package	Reference
Import and Export Raster data	raster	Hijmans et col. (2020)
	ncdf4	David Pierce (2019)
Import and Export Vector data	rgdal	Bivand et col. (2019)
Harmonization	raster	Hijmans et col. (2020)
	rgdal	Bivand et col. (2019)
Roth C Model	SoilR	Sierra and Mueller (2014)
Data Manipulation	abind	Plate (2016)
RothC Model, NPP MIAMI model	soilassessment	Omuto (2020)

Data requirements
(spatial SoilR GSP)

Vector

Country Limits (shapefile polygon)

SRC: EPSG: 4326. WGS84.

Geometry: Multipolygon

Objects: 1

Global Administrative Units Layer (GAUL) 2015

SOIL ORGANIC CARBON (GSOC, latest version)

SRC: EPSG: 4326. WGS84
Resolution: 1x1km
Depth: 0-30 cm
Format: raster, geotiff
Units: t C/ha

Climate Data

- Monthly 1981-2000:

Spin UP

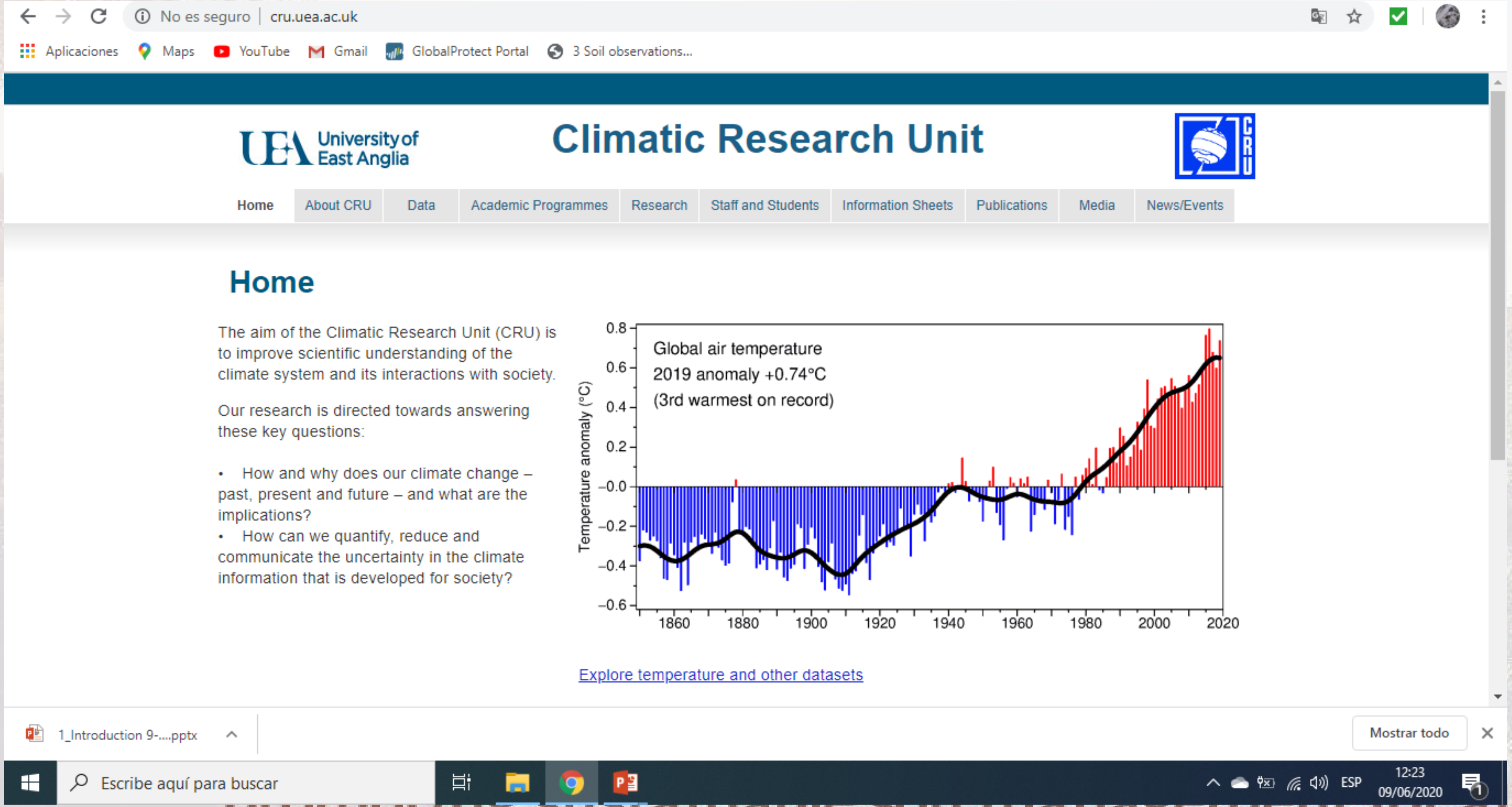
  - Precipitation (mm/month) 12 layers (one per month)
  - Air Temperature (°C) 12 layers (one per month)
  - Potential Evapotranspiration (mm/month) 12 layers (one per month)

- MIAMI model
  - Precipitation (mm/year) 20 layers (one per year) or
    240 layers (one permonth per year) (CRU layer arrengement)
  - Temperature (°C) 20 layers (one per year) or
    240 layers (one per month per year) (CRU layer arrengement)

Climate Data

- Monthly From 2001-2018/20
- Warm Up
  - Precipitation (mm/month) 216-240 layers (one per month per year) (CRU layer arrangement)
  - Temperature (°C) 216-240 layers (one per month per year) (CRU layer arrangement)
  - Potential Evapotranspiration (mm/month) 216-240 layers (one per month per year) (CRU layer arrangement)
- Forward
  - Precipitation (mm/month) 12 layers (one per month)
  - Temperature (°C) 12 layers (one per month)
  - Potential Evapotranspiration (mm/month) 12 layers (one per month)

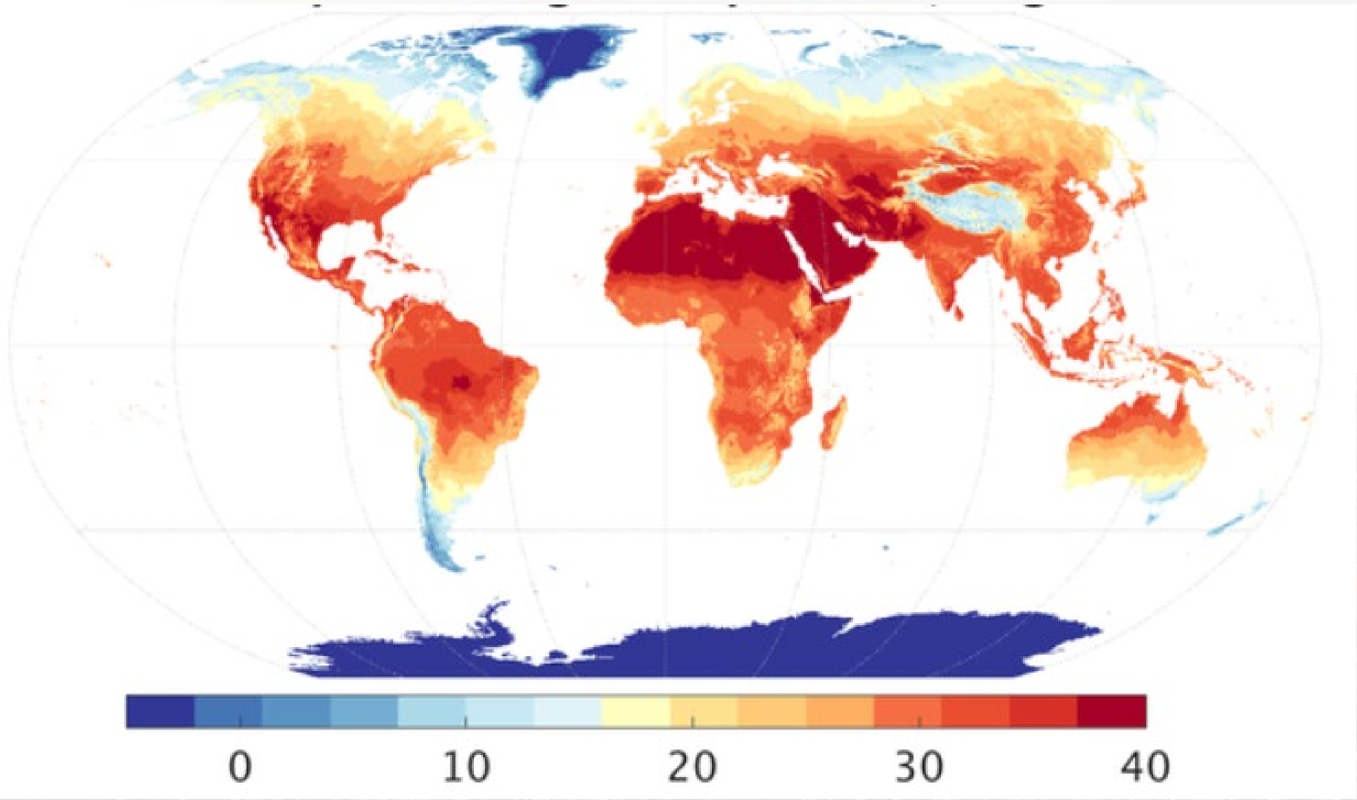
http://www.cru.uea.ac.uk/



Additional global climate data set

GEE and R scripts

- TerraClimate is a dataset of monthly climate for global terrestrial surfaces from 1958-2019
- monthly temporal resolution and a ~4-km
- GEE and R scripts to download and prepare the data for you AOI will be provided soon

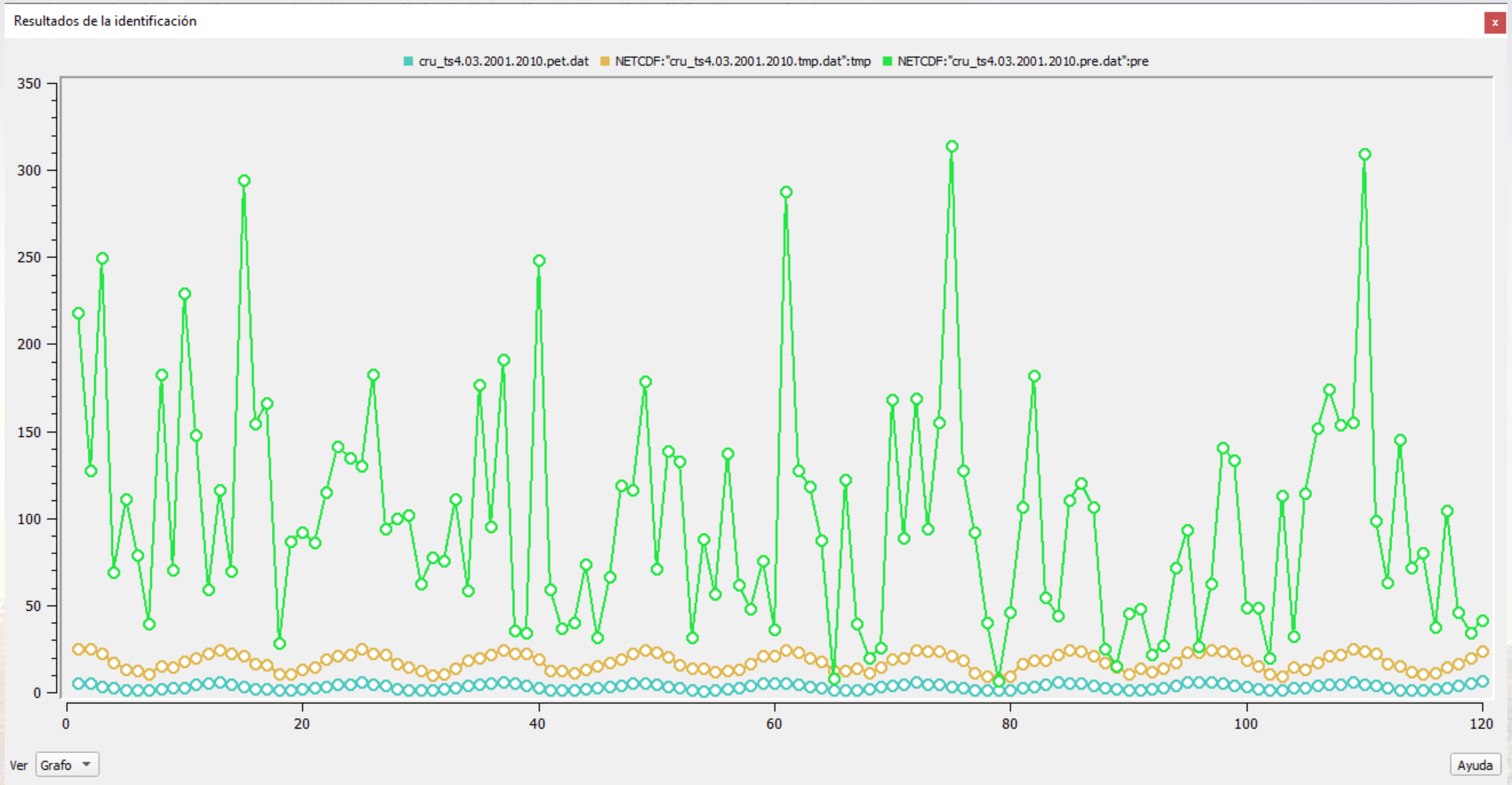


Climate Data

Temperature
cru_ts4.03.1981.1990.tmp.dat.nc
cru_ts4.03.1991.2000.tmp.dat.nc
cru_ts4.03.2001.2010.tmp.dat.nc
cru_ts4.03.2011.2018.tmp.dat.nc

Precipitation
cru_ts4.03.1981.1990.pre.dat.nc
cru_ts4.03.1991.2000.pre.dat.nc
cru_ts4.03.2001.2010.pre.dat.nc
cru_ts4.03.2011.2018.pre.dat.nc

Potential Evapotranspiration
cru_ts4.03.1981.1990.pet.dat.nc
cru_ts4.03.1991.2000.pet.dat.nc
cru_ts4.03.2001.2010.pet.dat.nc
cru_ts4.03.2011.2018.pet.dat.nc

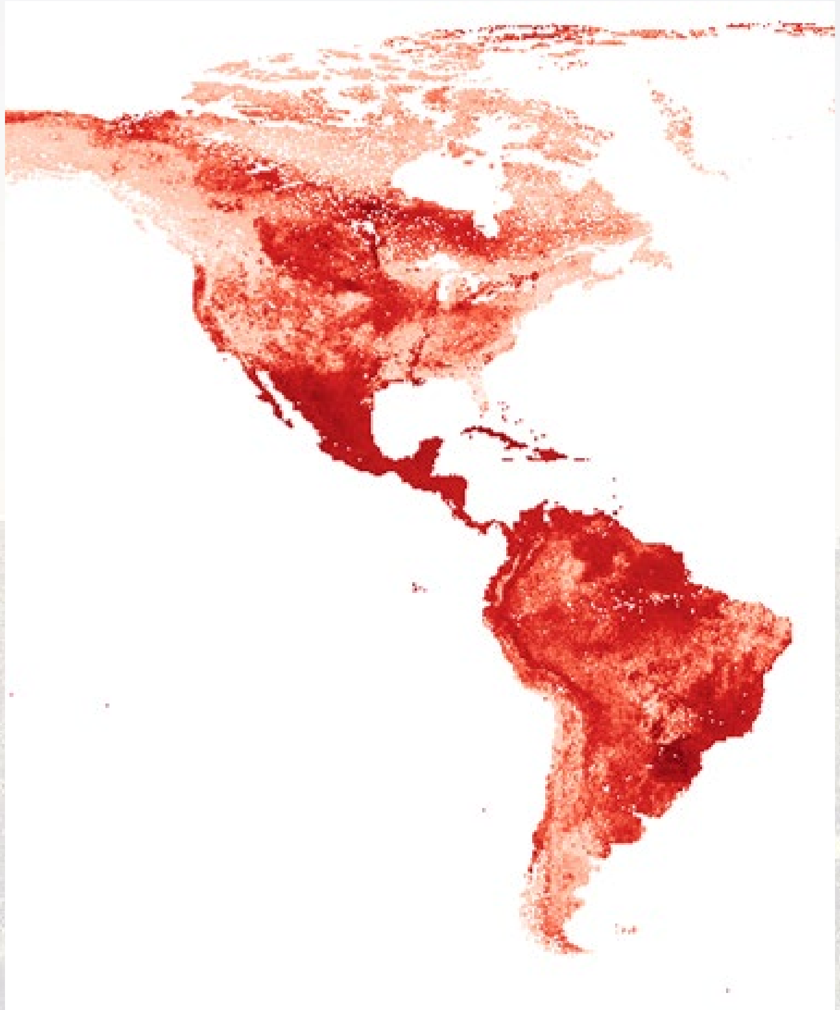


Resolution: 50 km or less (country data)
Format: .nc to geotiff
Units: mm, °C

Soil Data

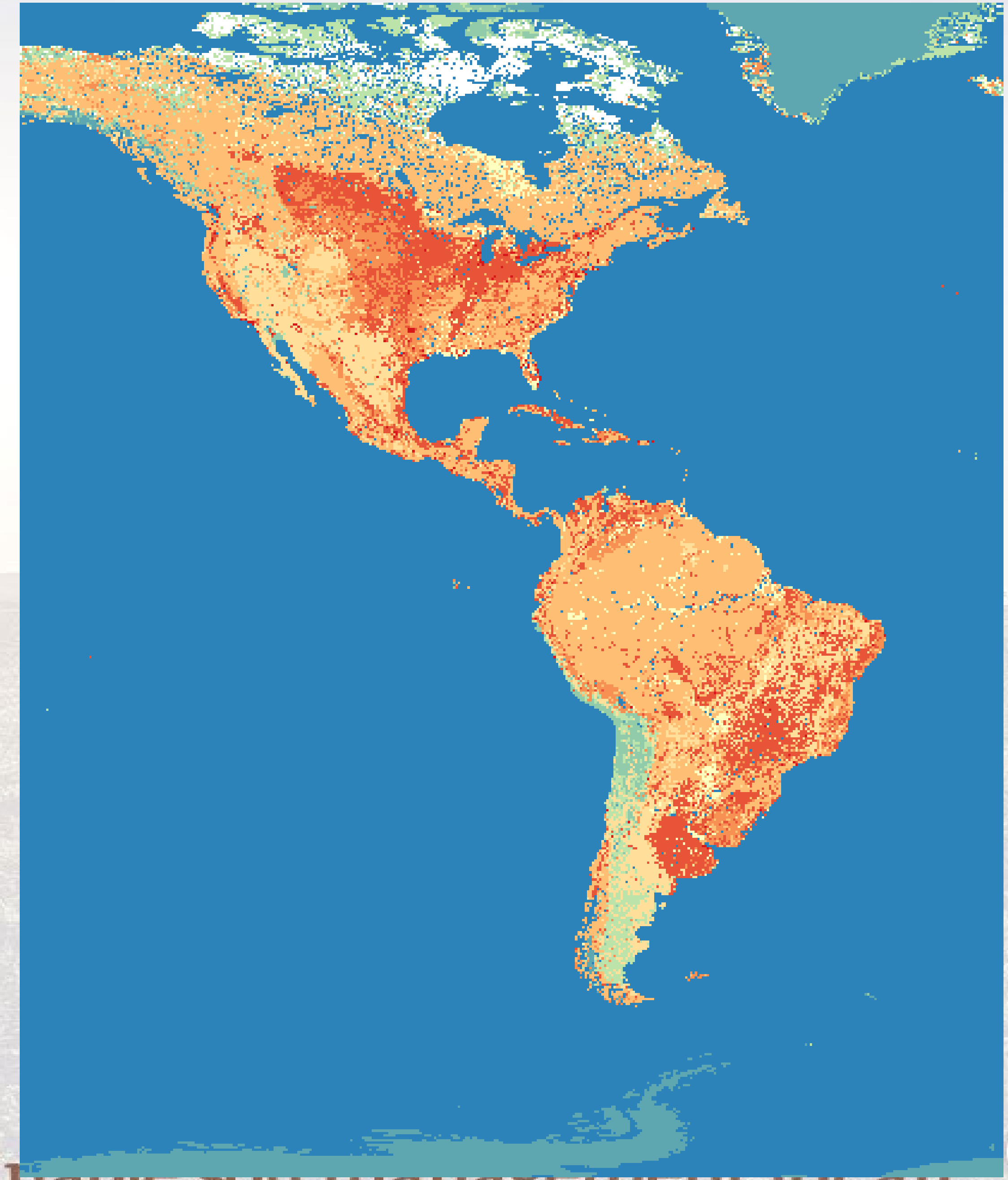
- CLAY LAYERS (Soilgrids)
- CLYPPT_M_sl1_250m_ll.tif
- CLYPPT_M_sl2_250m_ll.tif
- CLYPPT_M_sl3_250m_ll.tif
- CLYPPT_M_sl4_250m_ll.tif

SRC: EPSG: 4326. WGS84
Resolution: 1x1km
Depth: 0-30 cm
Format: raster, geotiff
Units: %



Land Use (from Land Cover)

- **Global Source: From ESA**
- **ESA_Land_Cover_11clases_FAO.tif**
- **(RECLASSIFIED ESA LAND COVER TO 12 classes)**
- **This file will be provided.**
- **Spatial Resolution: 300m x 300m**



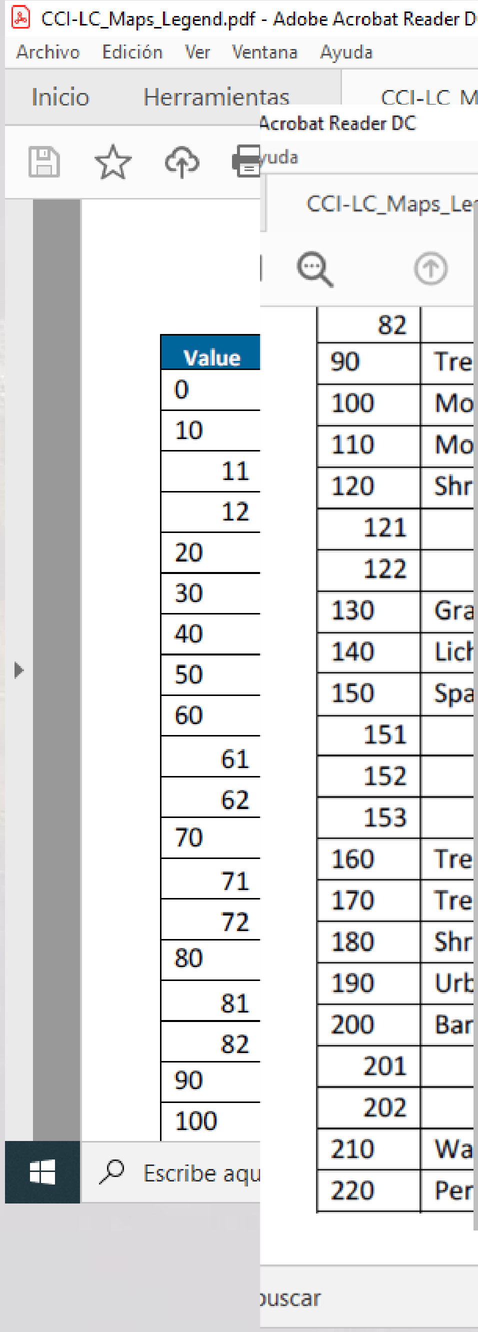
Other preferred National Source

SRC: EPSG: 4326. WGS84

Final Resolution: 1x1km

Format: raster, geotiff

Units: Classes Match FAO classes



0 = 0 No Data

190 = 1 Artificial

10 11 20 30 40 = 2 Croplands

130 = 3 Grassland

50 60 61 62 70 71 72 80 81 82 90 100 110 = 4 Tree Covered

120 121 122= 5 Shrubs Covered

160 180 = 6 Herbaceous vegetation flooded

170 = 7 Mangroves

150 151 152 153= 8 Sparse Vegetation

200 201 202 = 9 Baresoil

220 = 10 Snow and Glaciers

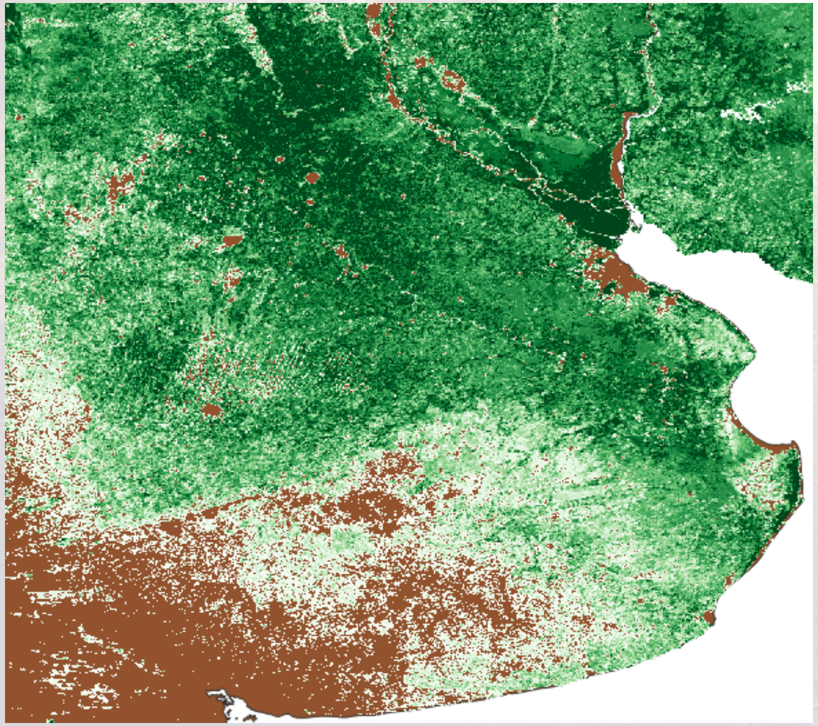
210 = 11 Waterbodies

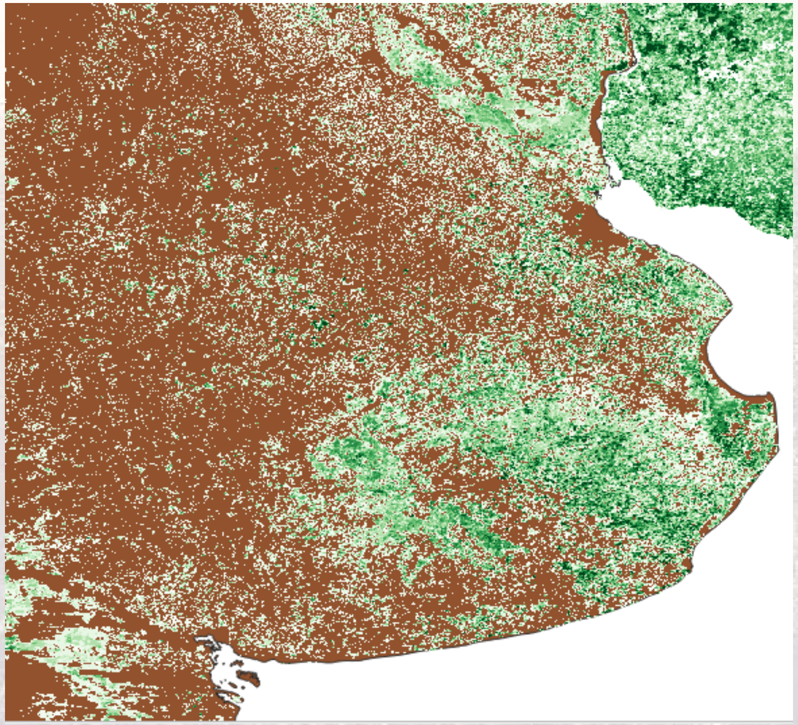
12 = 12 Treecrops

Soil/Vegetation cover

- Minimum: 12 layers (one per month) from MODIS NDVI.
- GEE (script)
- Other methods

SRC: EPSG: 4326.
WGS84
Resolution: 1x1km
Format: raster, geotiff
Units: 0.6 (covered) to 1.0 (bares soil)



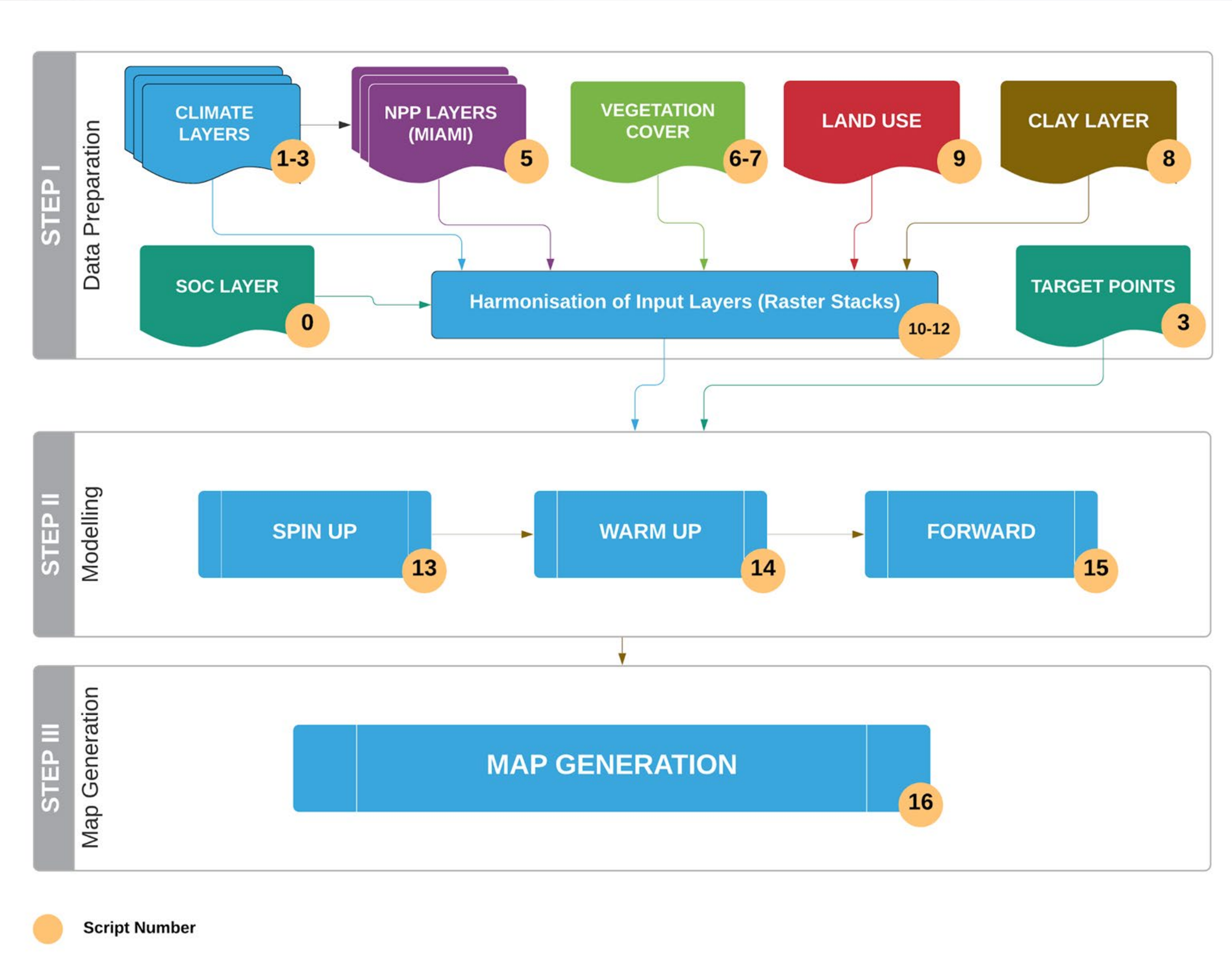


Summary. Inputs for the 3 Phases

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

Scripts - Sequence

scripts


STEP I
Data Preparation
CLIMATE LAYERS
1-3
NPP LAYERS (MIAMI)
5
VEGETATION COVER
6-7
LAND USE
9
CLAY LAYER
8
SOC LAYER
0
Harmonisation of Input Layers (Raster Stacks)
10-12
TARGET POINTS
3
STEP II
Modelling
SPIN UP
13
WARM UP
14
FORWARD
15
STEP III
Map Generation
MAP GENERATION
16
Script Number

Type of Layer	Script	Objective
SOC layer	0. R- Script number 0	Cut the soc layer by the area of interest polygon
Climate layers	1. R- Script number 1 2. R- Script number 2 3. R- Script number 3	Rearrangement of climate layers (CRU layers from .ncd to .tif)
NPP layers	5. R- Script number 5	Creation of NPP layers
Vegetation Cover (VC)	6. GEE Script number 6 (Google Earth Engine) 7. R- Script number 7	Creation of VC layers
Clay layers	8. R-Script number 8	Obtaining clay contents 0-30 cm from different depths (ISRIC)
Land Use layer	9. R-Script number 9	Re-classification into FAO land cover classes
STACK for SPIN UP	10. R-Script number 10	Stack input data layers for the spin up phase
STACK for WARM UP	11. R-Script number 11	Stack input data layers for the warm up phase
STACK for FORWARD	12. R-Script number 12	Stack input data layers for the forward phase
Target points	13. Qgis model script	Creation of target points
SPIN UP	14. R- Script number 13	Run long spin up phase
WARM UP	15. R- Script number 14	Run warm up phase
FORWARD	16. R- Script number 15	Run forward phase
POINTS TO RASTER	17. R- Script number 16	Rasterize points

Data harmonization

Model running

Maps creation

Folders

Nombre

- 0_SOC_MAP
- 1_CRU_variables
- 2_MIAMI_NPP
- 3_GEE_Veg_Cover
- 4_CLAY
- 5_LAND_USE
- 6_ROTH_C_STACK
- 7_TARGET_POINTS_COUNTRY
- 8_ROTH_C
- 9_MAPS
- INPUTS
- OUTPUTS

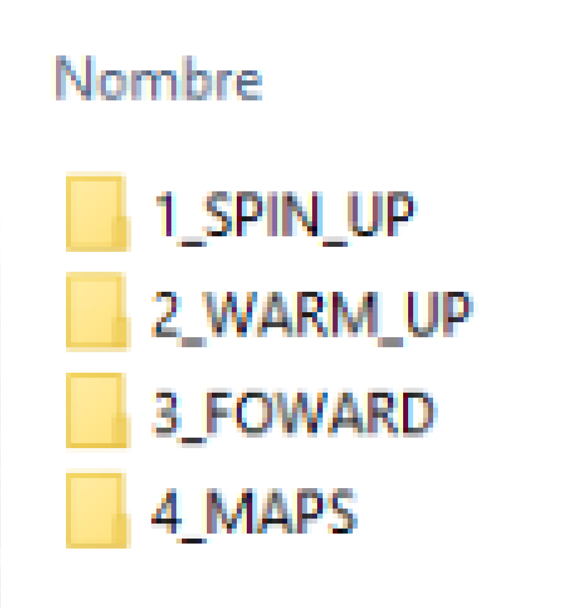
SCRIPTS (folders 0_SOC_MAP to 9_MAPS)

DIRECTORY : INPUTS

Nombre

- AOI_POLYGON
- CLAY
- COV
- CRU_LAYERS
- LAND_USE
- NPP
- SOC_MAP
- STACK
- TARGET_POINTS

DIRECTORY : OUTPUTS (MODEL)



Step 1 : Data preparation

Soc FAO : master layer

0_SOC_MAP_AOI.R

OBJETIVE: CROP SOC MAP BY USING COUNTRY POLYGON OR REGION OF INTERES

UNIT: [tn/ha]

Harmonization of Climate Layers (CRU)

1_CRU_variables_SPIN_UP.R
2_CRU_variables_WARM_UP.R
3_CRU_variables_for_NPP_MIAMI_MEAN_81-00.R

OBJETIVE: ARRANGE CLIMATE FILES (CRU FORMAT) TO BE USED IN THE MODELING PHASES

Units: [mm/month] [°C]

NPP (Net primary production) Layers

4_MIAMI_MODEL_NPP_MIAMI_MEAN_81-00.R

OBJETIVE : Estimate annual NPP (using MIAMI Model) for the 1981-2000 period.
Year to year NPP is estimated and then averaged.

Clay

8_Script_CLAY_from_ISRIC.R

OBJECTIVE: Estimate clay % 0-30 cm depth using weighted average (ISRIC Clay layers)

Unit: %

LAND USE

9_Land_Use_ESA_to_FAO_classes.R

OBJECTIVE: RE-CLASSIFY ESA (EUROPEAN SPACE AGENCY) COVER CLASSES TO FAO LAND USE CLASSES.

SOIL/VEGETATION COVER Layers: GEE-R

6_Vegetation_Cover_GEE_copy_to_code_Editor.txt
7_Veg_Cov_stack.R

OBJECTIVE: Generate a stack of 12 layers, one for each month that represents vegetation cover for each pixel.

- We will estimate Google Earth Engine for each pixel, as the number of images with vegetation from total images of a specified time series (assuming NDVI higher > 0.3 threshold)
- We will get a probability from 0 to 1,(being 0 never covered and 1 always covered)
- These values are then re-escalated to the vegetation cover factor (0.6 = covered; 1 = bare soil)

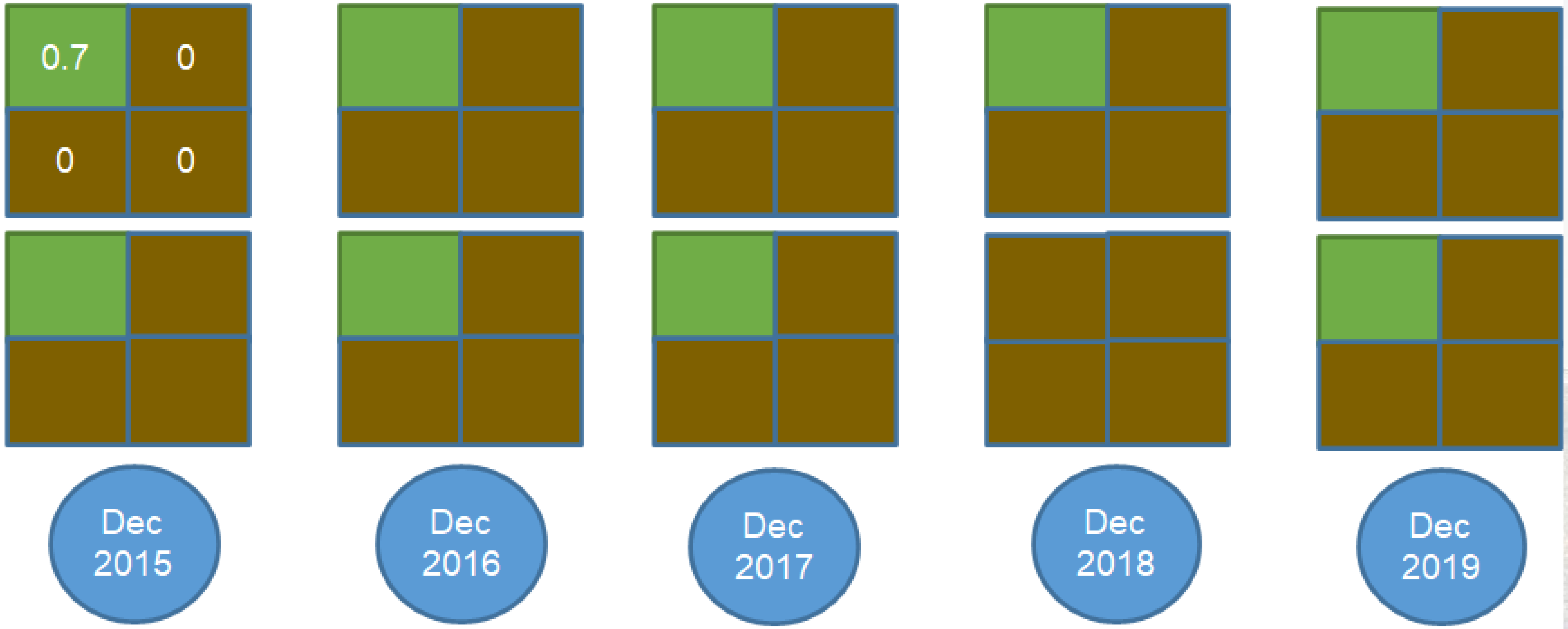
Final Unit: 0.6-1.0

Vegetation cover from Google Earth Engine

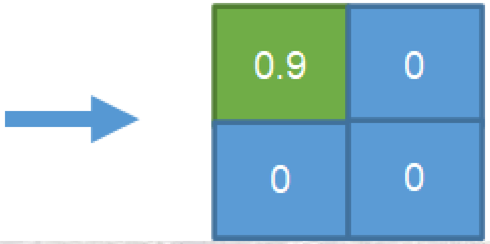
MOD13A2 v006 MODIS/Terra Vegetation Indices 16-Day L3 Global 1 km SIN Grid

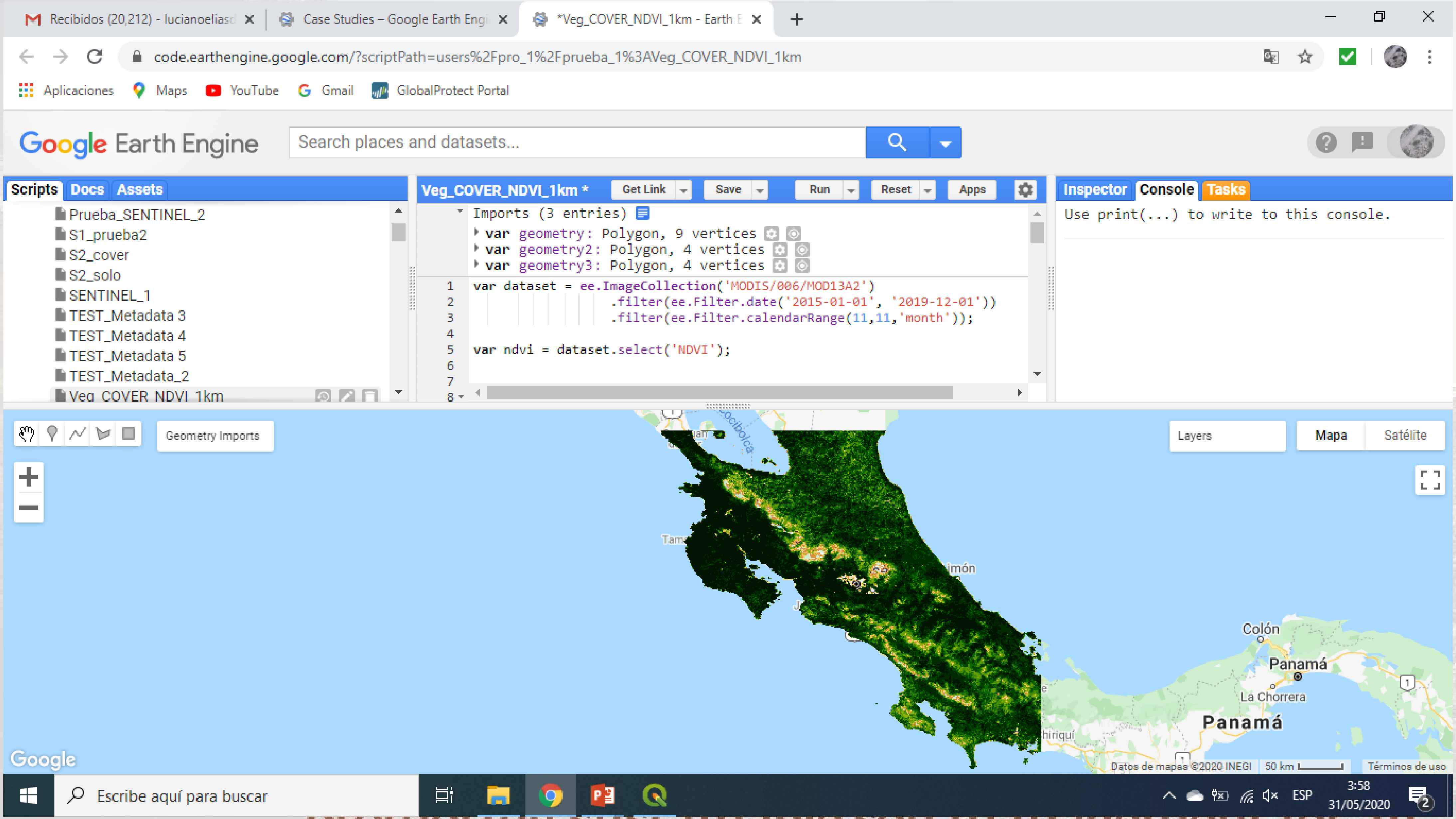
365/16 ≈ 22 Layers per year
22/12 ≈ 2 Layers per month

Total images = ~2 Layers per month x years of interest



$$P_{veg} = \frac{Number\ of\ images\ NDVI > 0.6}{Total\ images}$$





promoting sustainable soil management for all

HARMONIZATION OF LAYERS (generating Stacks)

10_SPIN_UP_STACK_V3.R
11_WARM_UP_STACK_V5.R
12_FOWARD_STACK.R

OBJECTIVE: GENERATE STACKS OF INPUT DATA LAYERS (USING GSOC FAO 1KM AS A MASTER LAYER) TO BE USED IN EACH MODELING PHASE : SPIN UP- WARM UP – FORWARD.

FOR THE WARM UP PHASE, CLIMATE LAYERS ARE NOT INCLUDED IN THE STACK DOR FILE SIZE RESTRICTIONS (NEAR 700 LAYERS).

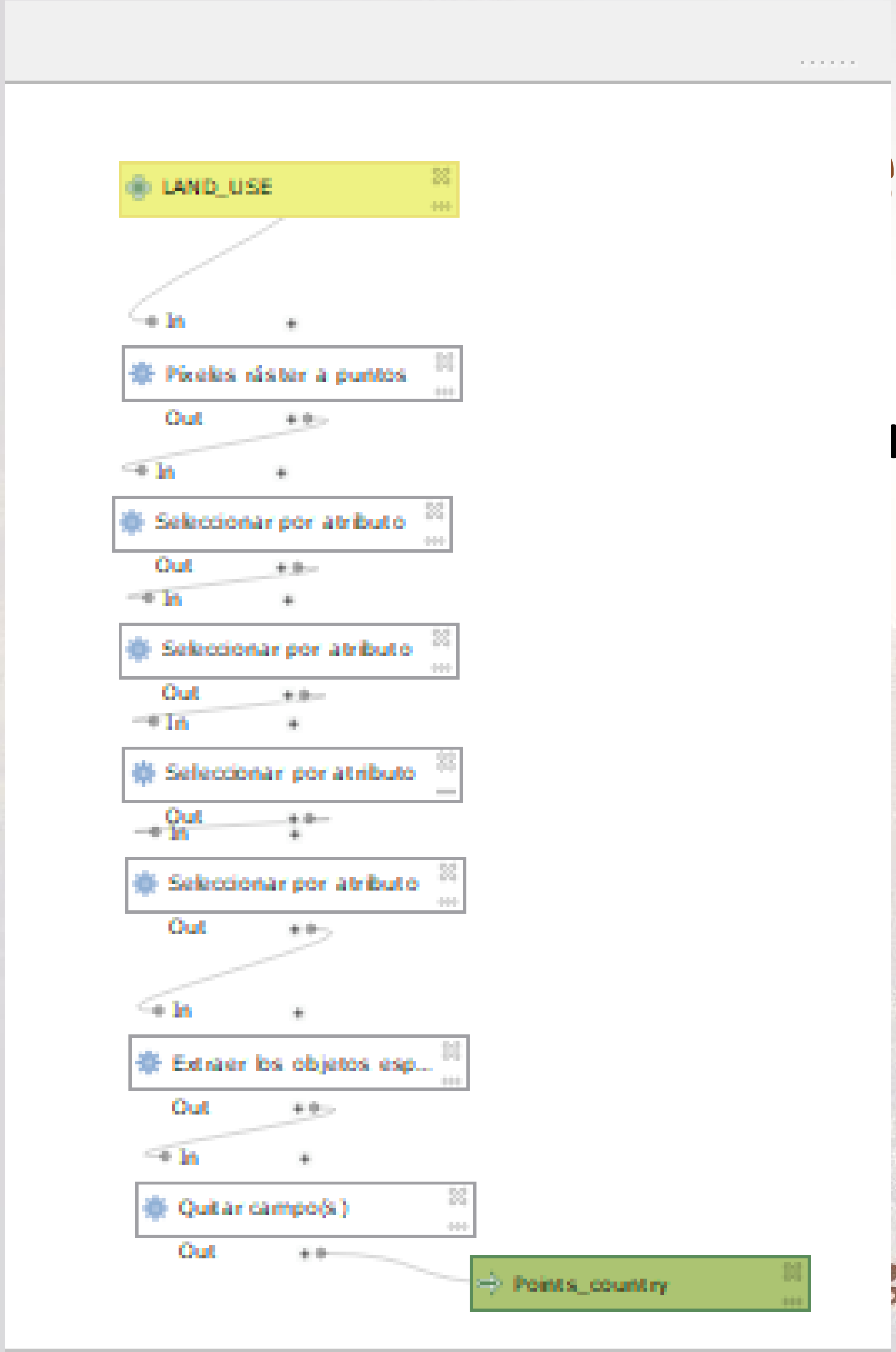
CREATING TARGET POINTS

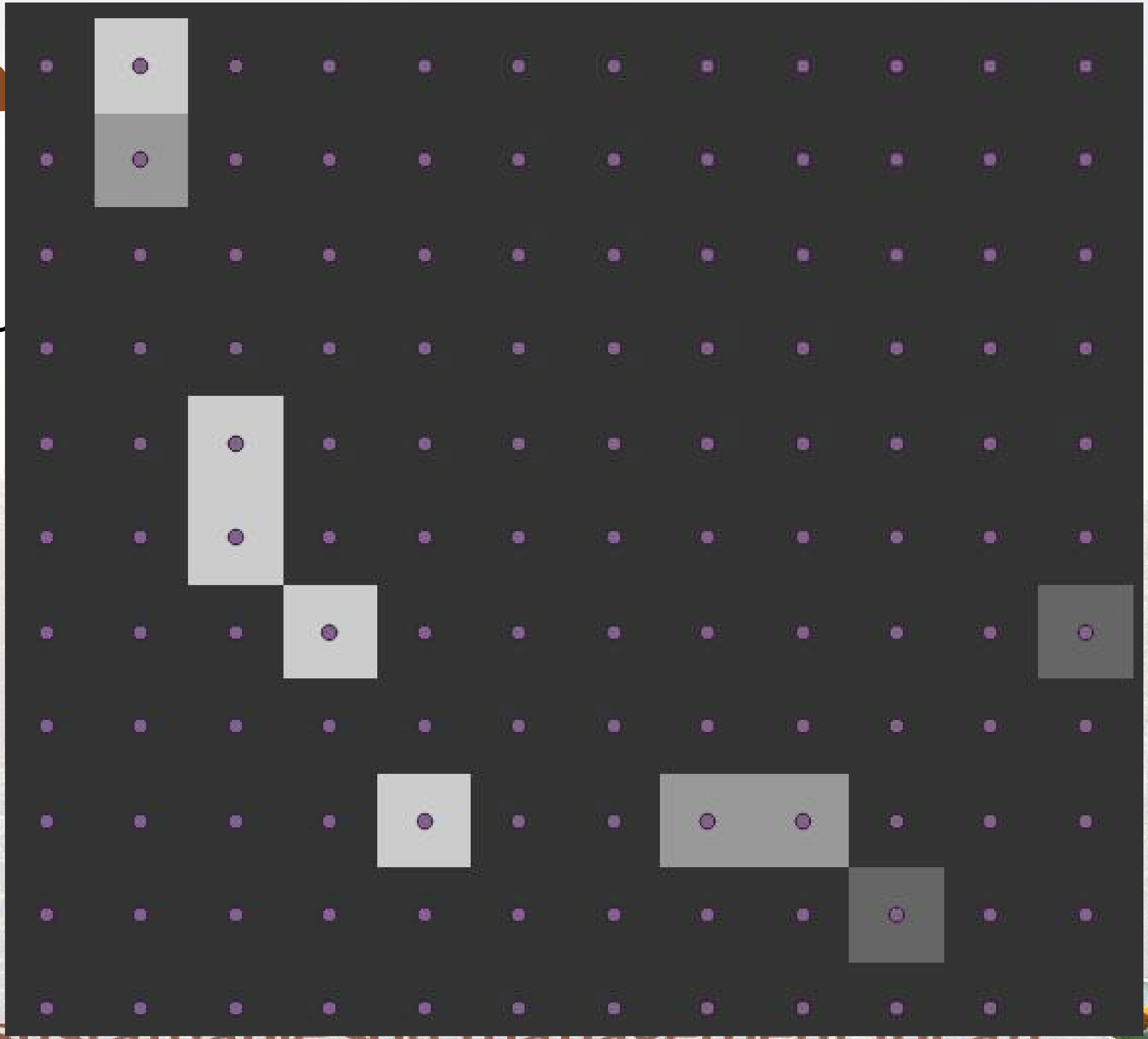
Qgis_Procedure_number_1.model3

OBJECTIVE : GENERATE TARGET POINTS WHERE THE MODEL IS TO BE RUN

SELECT ONLY LAND USES OF INTERESTS (AVOID WATER BODIES, NATIVE VEGETATION, FORESTS, DESSERT AREAS… WHERE NO MANAGEMENT IS TO BE IMPLEMENTED)

CAN BE MODIFIED DEPENDING ON COUNTRY INTERESTS (Eg. restoration of native vegetation)


LAND_USE
In
Píxeles ráster a puntos
Out
In
Seleccionar por atributo
Out
In
Seleccionar por atributo
Out
In
Seleccionar por atributo
Out
In
Seleccionar por atributo
Out
In
Extraer los objetos esp...
Out
In
Quitar campo(s)
Out
Points_country



Step 2 : Running the model

Running the Roth C - SoilR

13_ROTH_C_SPIN_UP_UNC_v2.R
14_ROTH_C_WARM_UP_UNC_v3.R
15_ROTH_C_FOWARD_UNC_v3.R

SPIN UP: THE OBJECTIVE IS TO ESTIMATE C INPUT LEVELS TO REACH TFAO GSOCmap SOC STOCKS. ADDITIONALLY, TO ESTIMATE INITIAL SOC STOCKS OF EACH POOL

WARM UP: THE OBJECTIVE IS TO C INPUTS AND SOC STOCKS USING MONTHLY DATA FROM THE LAST 20 YEARS (CLIMATE- NPP - LAND USE (OPTIONAL))

FORWARD: THE OBJECTIVE IS TO PROJECT SOC STOCKS PER PIXEL AND ESTIMATE THE UNCERTAINTY OF THAT PREDICTION

Step 3 : From Points to Rasters

FROM POINTS TO RASTERS

From points to rasters

16_Points_To_Raster.R

OBJECTIVE:

MODELING OUTPUT WILL BE A ´POINT´ VECTOR FILE (1 POINT PER PIXEL), WITH INFORMATION ABOUT THE THREE SCENARIOS AND THE BASE SCENARIO (BAU).

IT WILL ALSO CONTAIN INFORMATION ON THE UNCERTAINTY OF THE SIMULATED DATA. THESE VALUES ARE SAVED IN A TABLE ATTACHED TO THOSE POINTS (ESRI SHAPEFILE FORMAT).

THIS LAST STEP WILL TRANSFORM THESE POINTS TO RASTER FILES, ONE FOR EACH TARGET MAP.

PRODUCTS

Final SOC Stocks (tC/ha)

&

Uncertainties (%)

Pergamino_GSOCseq_finalSOC_BAU_Map030.tif
Pergamino_GSOCseq_finalSOC_SSM1_Map030.tif
Pergamino_GSOCseq_finalSOC_SSM2_Map030.tif
Pergamino_GSOCseq_finalSOC_SSM3_Map030.tif

Pergamino_GSOCseq_SSM_UncertaintyMap030.tif
Pergamino_GSOCseq_T0_Map030.tif
Pergamino_GSOCseq_T0_UncertaintyMap030.tif

ABSOLUTE DIFFERENCES (SCENARIO – T0) In tC/ha

Pergamino_GSOCseq_AbsDiff_BAU_Map030.tif
Pergamino_GSOCseq_AbsDiff_SSM1_Map030.tif
Pergamino_GSOCseq_AbsDiff_SSM2_Map030.tif
Pergamino_GSOCseq_AbsDiff_SSM3_Map030.tif

ABSOLUTE RATES : ABS DIF./20
In tC/ha/year

- Pergamino_GSOCseq_ASR_BAU_Map030.tif
- Pergamino_GSOCseq_ASR_BAU_UncertaintyMap030.tif
- Pergamino_GSOCseq_ASR_SSM1_Map030.tif
- Pergamino_GSOCseq_ASR_SSM1_UncertaintyMap030.tif
- Pergamino_GSOCseq_ASR_SSM2_Map030.tif
- Pergamino_GSOCseq_ASR_SSM2_UncertaintyMap030.tif
- Pergamino_GSOCseq_ASR_SSM3_Map030.tif
- Pergamino_GSOCseq_ASR_SSM3_UncertaintyMap030.tif

RELATIVE DIFFERENCES: (SCENARIO – BAU) In tC/ha

- Pergamino_GSOCseq_RelDiff_SSM1_Map030.tif
- Pergamino_GSOCseq_RelDiff_SSM2_Map030.tif
- Pergamino_GSOCseq_RelDiff_SSM3_Map030.tif

RELATIVE RATES : REL. DIF./ 20
In tC/ha/year

Pergamino_GSOCseq_RSR_SSM1_Map030.tif
Pergamino_GSOCseq_RSR_SSM1_UncertaintyMap030.tif
Pergamino_GSOCseq_RSR_SSM2_Map030.tif
Pergamino_GSOCseq_RSR_SSM2_UncertaintyMap030.tif
Pergamino_GSOCseq_RSR_SSM3_Map030.tif
Pergamino_GSOCseq_RSR_SSM3_UncertaintyMap030.tif

Thank You

guillermoepperalta@gmail.com
lucianoeliasdipaolo@gmail.com