Dynamic vegetation modelling and applications with CARAIB

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OUTLINE

1) Introduction
2) The CARAIB model
3) Example of results and model validation
4) Interannual variability
5) Climate change impacts on ecosystems
6) Integrating crops and ecosystem services (VOTES)
7) Conclusions & perspectives: towards an integrated tool for upscaling

Introduction

Dynamic vegetation models (DVM) are complex tools that can describe the response of vegetation (plant functional types or species) to **climate change**.

VEGETATION DISTRIBUTION MODELS (biomes, species)
- equilibrium biome models (Box, 1981; Prentice et al. 1992)
- forest succession models (gap models)
- niche-based models (Thuiller et al., 2005)
- species dispersal models

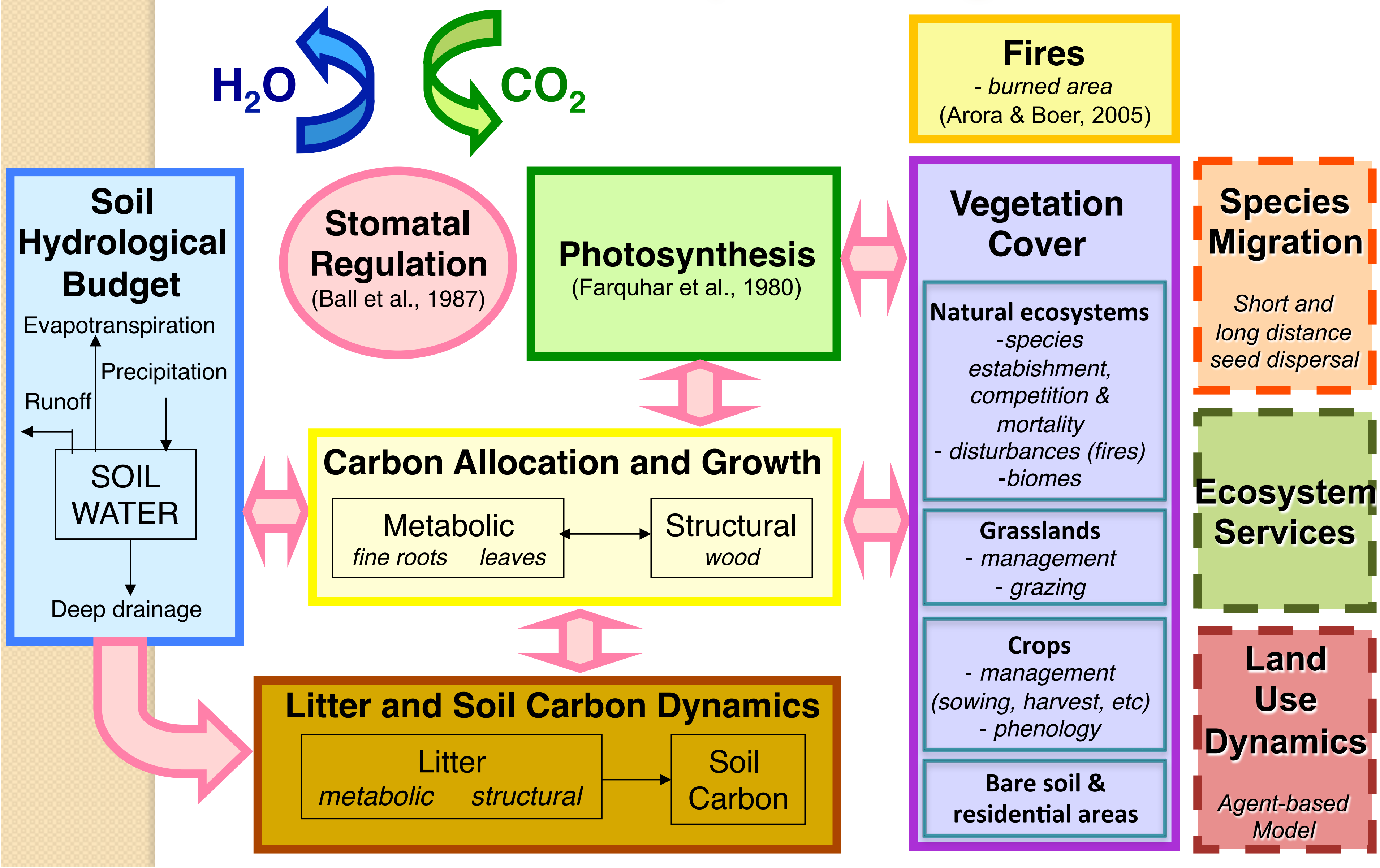
BIOGEOCHEMICAL MODELS (NPP, NEE, biomass, soil C)
- photosynthesis models (Farqhuar et al., 1980)
- terrestrial biosphere models (Potsdam 1995 models)

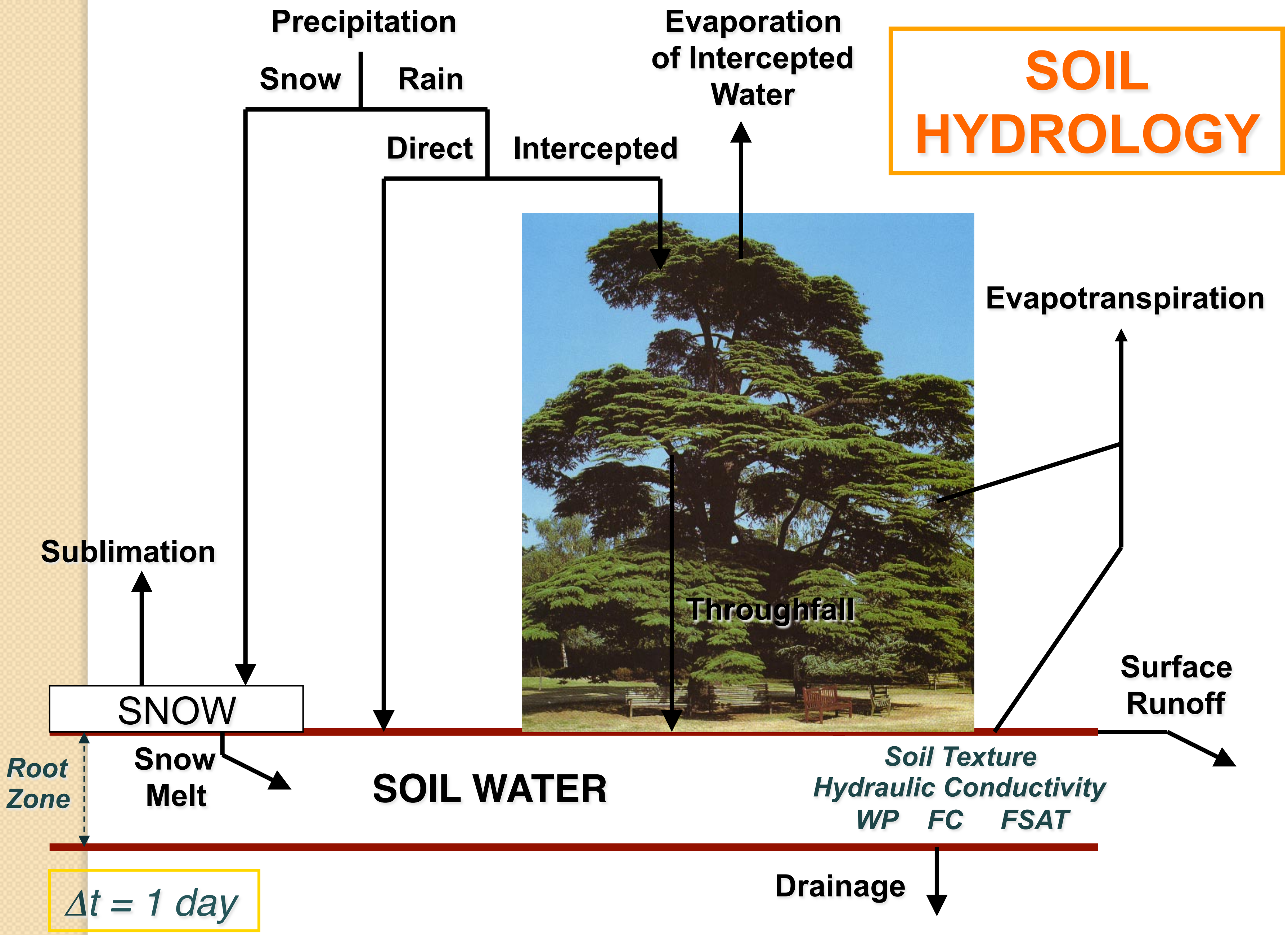
(BIO)PHYSICAL MODELS (energy exchange, water cycle)
- « bucket models »
- SVAT (GCM surface schemes)

DYNAMIC (GLOBAL) VEGETATION MODEL, D(G)VM
- soil hydrology
- vegetation physiology
- vegetation phenology
- carbon budget
- nutrient budgets
- vegetation dynamics (species establishment, competition & mortality)
- disturbances (fires, storms, grazing)
- trace gas emission (VOC)
- ecosystem management
- ecosystem goods and services (EGS)

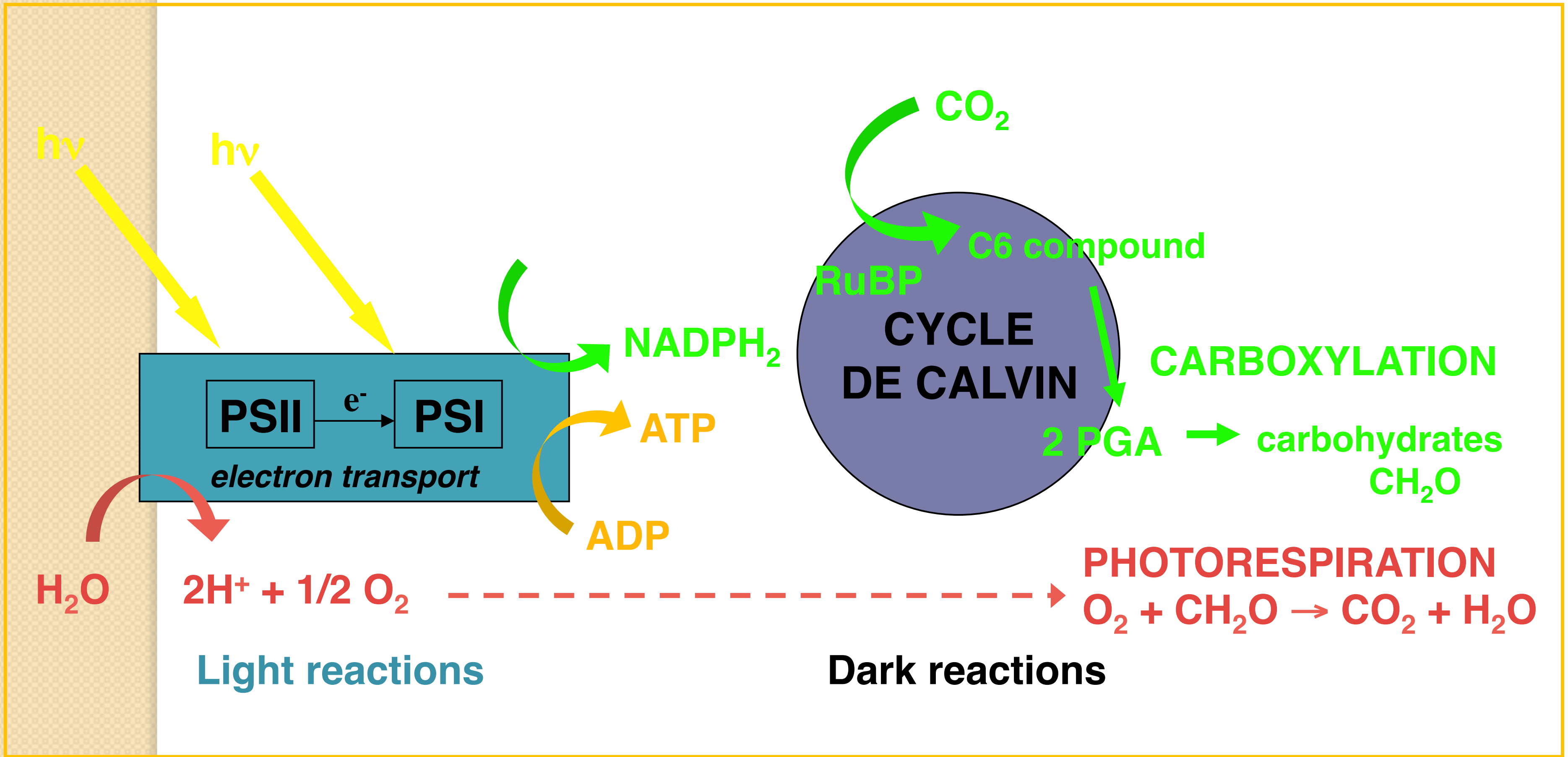
The CARAIB Model

CARAIB Dynamic Vegetation Model




SOIL HYDROLOGY
Precipitation
Snow
Rain
Direct
Intercepted
Evaporation of Intercepted Water
Evapotranspiration
Sublimation
Throughfall
SNOW
Snow Melt
Surface Runoff
Root Zone
SOIL WATER
Soil Texture
Hydraulic Conductivity
WP FC FSAT
Drainage
Δt = 1 day

PHOTOSYNTHESIS



PHOTOSYNTHETIC ASSIMILATION MODEL
(Farquhar et al., 1980)

$$A_1 = \frac{J(I_{APAR}, J_{max})}{4} \cdot \frac{c_i - \Gamma_*}{c_i + 2\Gamma_*}$$

(limitation par le transport d' électrons → réactions claires)

$$A_2 = V_{c,max} \cdot \frac{c_i - \Gamma_*}{c_i + K_c(1 + \frac{O_2}{K_o})}$$

(limitation par la Rubisco → réactions sombres)

$$A = \min\,(A_1, A_2)$$

(assimilation photosynthétique brute)

avec:

$\Gamma_* = 0.21\ K_c\ O_2/(2\ K_o)$ = compensation point in the absence of dark respiration

c_i, O_2 = intercellular concentrations in CO_2 and O_2

K_c, K_o = Michaelis-Menten constants for CO_2 (carboxylation) and O_2 (photorespiration)

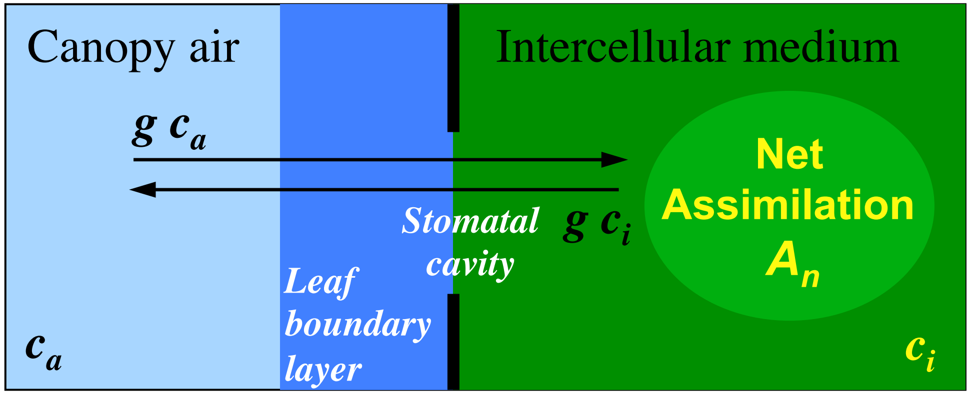
$J(I_{APAR}, J_{max})$ = potential rate of electron transport (depends on absorbed PAR radiation I_{APAR} and limited to J_{max})

Vc,max = Rubisco maximum synthesis capacity (dep. on T, C/N, SLA)

STOMATAL REGULATION AND CO_2 BUDGET OF THE LEAF

Leaf CO_2 budget:

$$g\,c_a = g\,c_i + A_n$$



Net assimilation (μmol C m_{leaf}^{-2} s^{-1}):

$$A_n = A - R_d$$

Dark respiration (mitochondria):

$$R_d = R_d\,(T, C/N)$$

Conductances and resistances:

Conductance: $g^{-1} = g_b^{-1} + g_s^{-1}$

Resistance: $r = r_b + r_s$

$$g_s = g_0 + g_1 \,.\, \Theta_{strs} \,.\, A_n \,/\, [(c_a - \Gamma).(1+VPD/VPD_0)]$$

→ **a 3rd degree polynomial equation is obtained which can be solved analytically or numerically with the Newton-Raphson method**

LEAF WATER FLUX: TRANSPIRATION

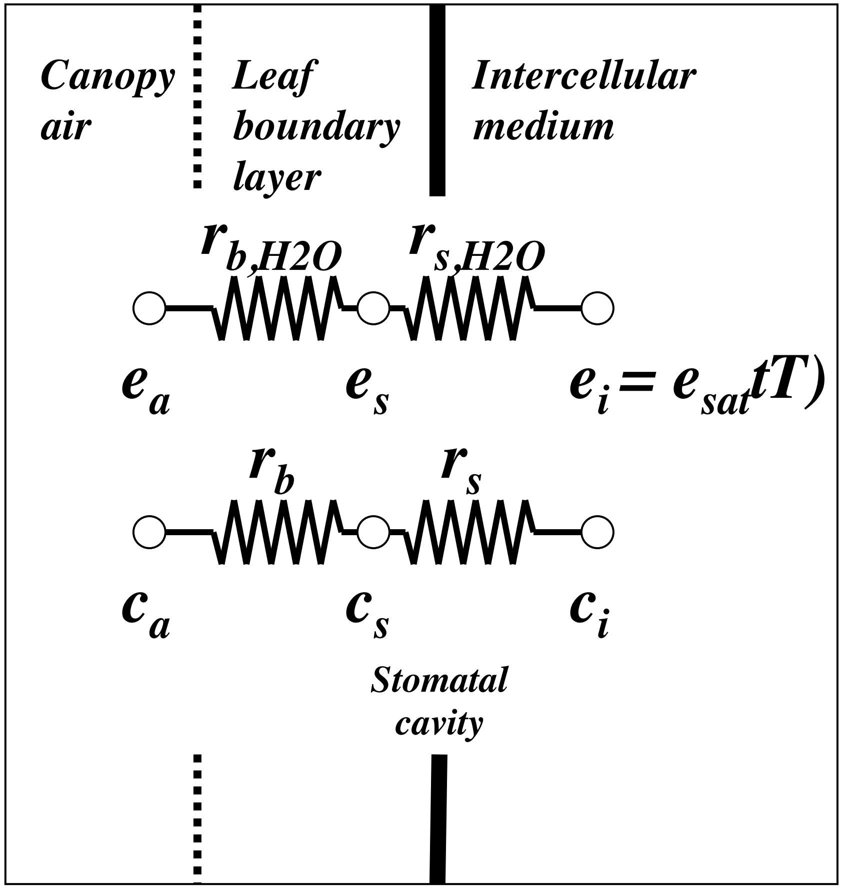
Transpiration flux per square meter of leaf:

$$E_{tr} = g_{H2O}\,(e_{sat}(T)-e_a)/RT$$

Conductance with respect to water:

$$g_{H2O}^{-1} = r_{H2O} = r_{b,H2O}+r_{s,H2O}$$

$$r_{b,H2O}= r_b\,/1.37 + r_s\,/1.6$$



Stomatal Regulation

c_a — R_a — R_{bl} — R_s — c_i

$c_i = c_a - A_n/g$

$g = 1/(R_a+R_{bl}+R_s)$

$1/R_s = g_0+g_1A_nh_s/(c_a-\Gamma)$

Photosynthesis

$A_n = A - R_d$

$A = \min(A_j,A_v)$

$A_j=A_j(APAR,c_i,T)$

$A_v = A_v(V_{cmax}, c_i, T)$

- C_3/C_4 modules
- sunlit/shaded
- plant-dependent parameters

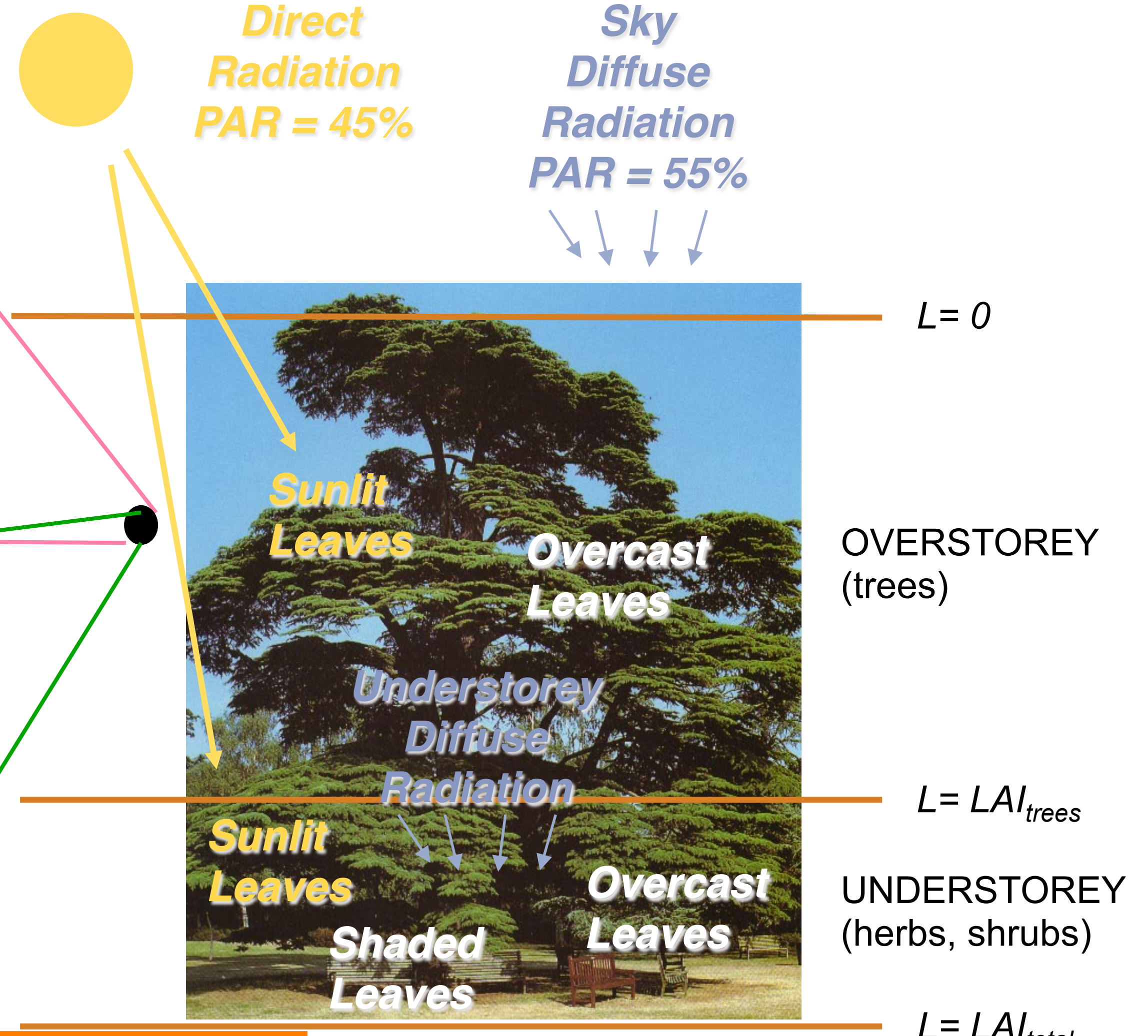
Canopy Model

Radiation transfer

2 storeys

3 types of leaves per plant type

$A_n(\text{canopy}) = \Sigma A_{n,l}$



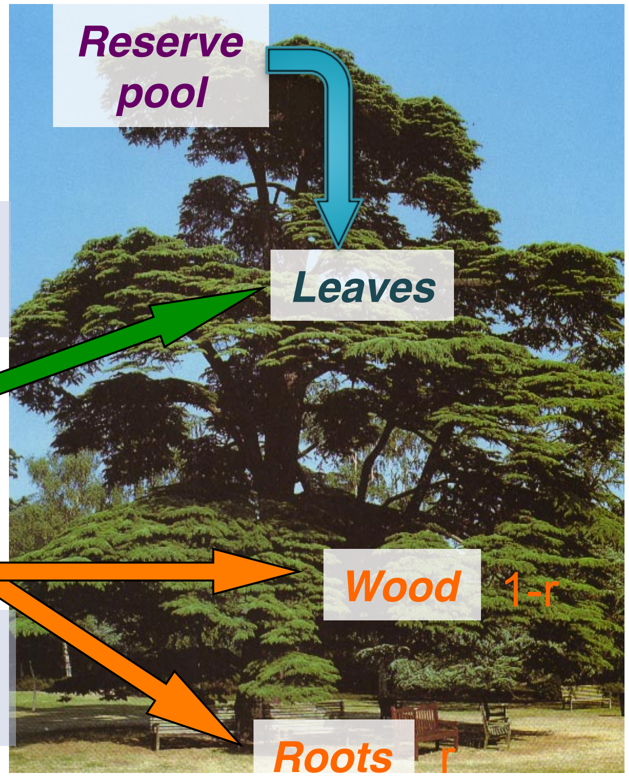
CANOPY MODEL

The allocation scheme in CARAIB

CARBON ALLOCATION

Metabolic carbon
S

Photosynthetic products



Structural carbon
1-S

AUTOTROPHIC RESPIRATION

Maintenance respiration

- proportional to carbon content of reservoir
- temperature-dependent

Growth respiration

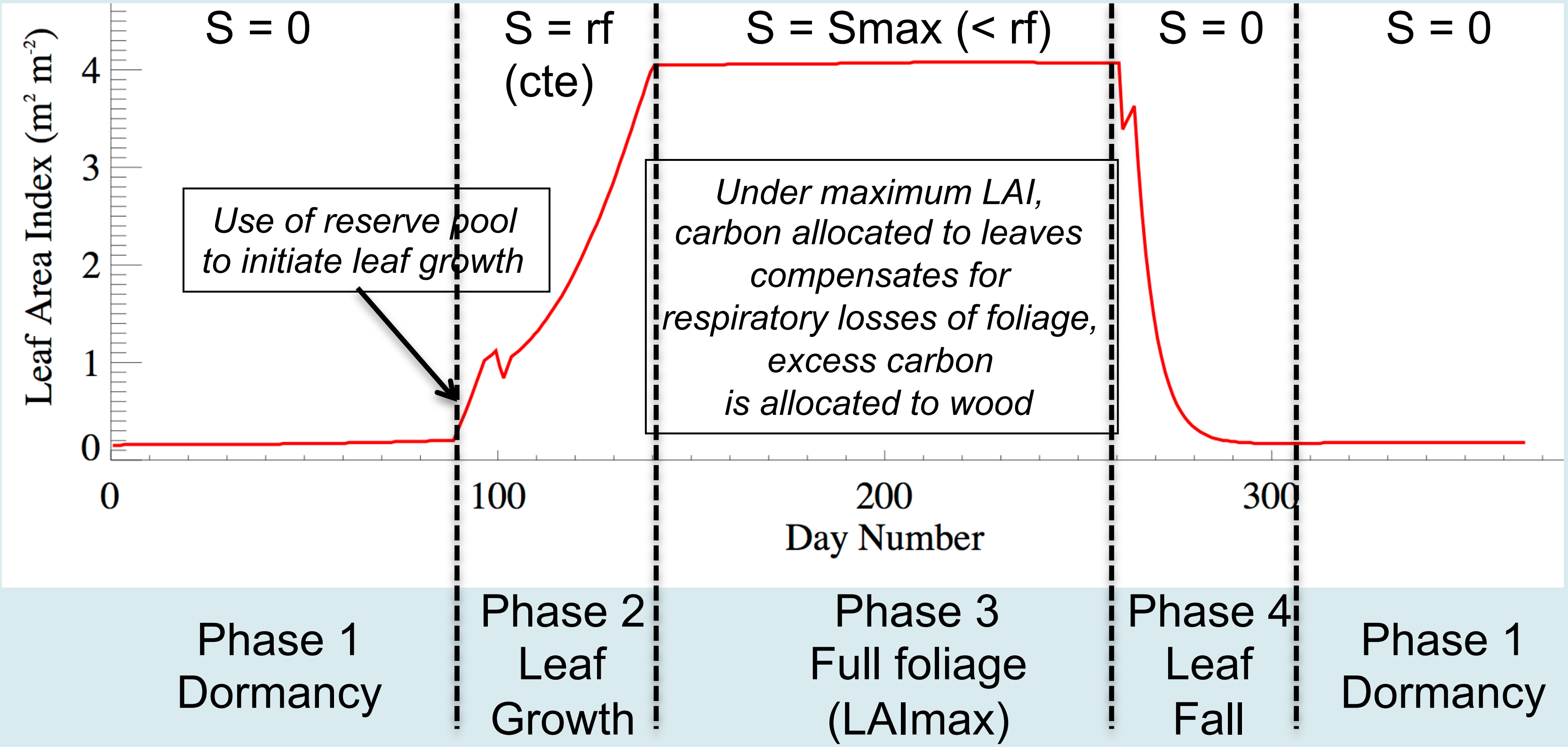
20% of input flux of reservoir

S = fraction of photosynthetic products allocated to leaves, varies with phenological phase
r = fixed ratio of roots in the structural reservoir (*a posteriori*, not dynamic) calculated from fixed root:shoot ratio for each species

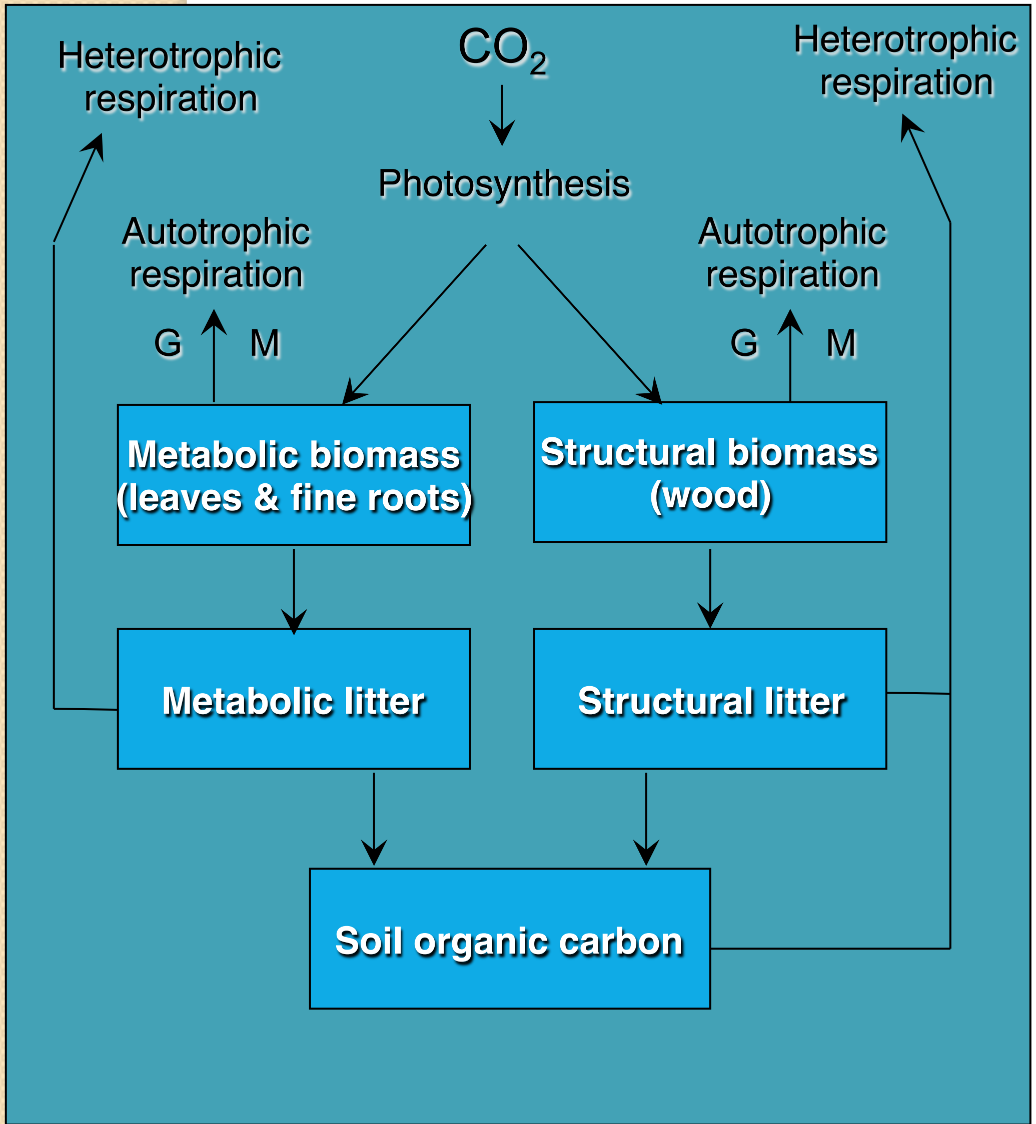
The allocation scheme in CARAIB

LAI max = min (LAImax_wood, LAImax_transpi)

- ➔ LAImax_wood = maximum LAI linked to wood biomass
- ➔ LAImax_transpi = maximum LAI allowed by average transpiration over vegetation period



RESERVOIRS AND FLUXES (for each PFT/BAG)



GPP = **Gross Primary Productivity (photosynthesis)**

R_a = **Autotrophic respiration (plant respiration)**

NPP = **Net Primary Productivity**
$= GPP - R_a$

R_h = **Heterotrophic respiration (animals, fungi, bacteria)**

NEE = **Net Ecosystem Exchange**
$= R_h - NPP = R_h + R_a - GPP$

NEP = **Net Ecosystem Productivity**
$= NPP - R_h = - NEE$

NBP = **Net Biome Productivity**
$= NEP - D – F – H$

D = losses through rivers
F = losses due to fires
H = harvest losses

Plant Functional Types (PFTs)

- *photosynthesis & growth calculated for all PFTs*
- *stress/germination parameters evaluated from present-day distribution*
- *competition between PFTs to fill gaps produced by natural or stress-induced mortality*

Global Classification

1. C3 herbs (humid)
2. C3 herbs (dry)
3. C4 herbs
4. Broadleaved summergreen arctic shrubs
5. Broadleaved summergreen boreal/temperate cold shrubs
6. Broadleaved summergreen temperate warm shrubs
7. Broadleaved evergreen boreal/temperate cold shrubs
8. Broadleaved evergreen temperate warm shrubs
9. Broadleaved evergreen xeric shrubs
10. Subdesertic shrubs
11. Tropical shrubs
12. Needleleaved evergreen boreal/temperate cold trees
13. Needleleaved evergreen temperate cool trees
14. Needleleaved evergreen supra-mediterranean trees
15. Needleleaved evergreen meso-mediterranean trees
16. Needleleaved evergreen subtropical trees
17. Needleleaved summergreen boreal/temperate cold trees
18. Needleleaved summergreen subtropical swamp trees
19. Broadleaved evergreen meso-mediterranean trees
20. Broadleaved evergreen thermo-mediterranean trees
21. Broadleaved evergreen subtropical trees
22. Broadleaved summergreen boreal/temperate cold trees
23. Broadleaved summergreen temperate cool trees
24. Broadleaved summergreen temperate warm trees
25. Broadleaved raingreen tropical trees
26. Broadleaved evergreen tropical trees

PFT 01 : C3 herbs (« humid »)	*Poaceae*
PFT 02 : C3 herbs (« dry »)	*Asteraceae*
PFT 03 : C4 herbs	all C4 herbaceous plants
PFT 04 : Broadleaved summergreen arctic shrubs	*Alnus viridis, Betula nana, Salix nana, Arctostaphylos, A. alpinus, Hippophae rhamnoides*
PFT 05 : Broadleaved summergreen boreal/temperate cold shrubs	*Sambucus, Frangula alnus, Lonicera, Prunus, Rubus, Sorbus, Vaccinium, Viburnum*
PFT 06 : Broadleaved summergreen temperate warm shrubs	*Berberis vul., Crataegus, Euonymus europaeus, Genista, Rhamnus, R. catharticus*
PFT 07 : Broadleaved evergreen boreal/temperate cold shrubs	*Artostaphylos uva-ursi, Calluna vul., Daphne*
PFT 08 : Broadleaved evergreen temperate warm shrubs	*Buxus sempervirens,Hedera helix, Ilex aquifolium, Ligustrum vulgare, Viscum*
PFT 09 : Broadleaved evergreen xeric shrubs	*Cistus, Myrtus*
PFT 10 : Subdesertic shrubs	*Nitraria*
PFT 11 : Tropical shrubs	*Aegiceras corniculatum, Ceriops tagal, Kandelia obovata, Rhizophora mucronata, Cassine*
PFT 12 : Needleleaved evergreen boreal/temperate cold trees	Cupressaceae, *Juniperus, J. communis, Abies, A. alba, Picea abies, P. omorika, Pinus sylvestris*
PFT 13 : Needleleaved evergreen temperate cool trees	*Taxus, Chamaecyparis, Pseudotsuga menziesi, Sequoia sempervirens, Thuja orientalis, Tsuga diversifolia, Pinus nigra*
PFT 14 : Needleleaved evergreen supra-Mediterranean trees	*Cedrus*
PFT 15 : Needleleaved evergreen meso-Mediterranean trees	*Pinus halepensis, Pinus pinaster, Cupressus, Tetraclinis*
PFT 16 : Needleleaved evergreen subtropical trees	*Sciadopitys, Cathaya, Keteleeria, Taiwania, Torreya, Athrotaxis*
PFT 17 : Needleleaved summergreen boreal/temperate cold trees	*Larix*
PFT 18 : Needleleaved summergreen subtropical swamp trees	*Taxodium, Glyptostrobus*
PFT 19 : Broadleaved evergreen meso-Mediterranean trees	*Quercus ilex, Quercus suber, Phillyrea, Arbutus, Quercus troyana*
PFT 20 : Broadleaved evergreen thermo-Mediterranean trees	*Olea europaea, Pistacia*
PFT 21 : Broadleaved evergreen subtropical trees	*Alangium, Castanopsis, Fatsia japonica, Gordonia, Lindera, Neolitsea, Reevesia, Sassafras*
PFT 22 : Broadleaved summergreen boreal/temperate cold trees	*Alnus, Alnus glutinosa, Corylus avellana, Quercus, Quercus robur, Populus, Tilia, Betula, Salix*
PFT 23 : Broadleaved summergreen temperate cool trees	*Acer, A. campestre, Carpinus betulus, Fagus sylvatica, Tilia cordata, Tilia platyphyllos, Fraxinus excelsior, Ulmus, Aesculus rubicunda, Populus cathayana, Quercus castaneaefolia, Quercus lobata, Tilia japonica, Ulmus davidiana*
PFT 24 : Broadleaved summergreen temperate warm trees	*Castanea, Juglans, Ostrya, Quercus pubescens, Q. benthamii, Craigia, Diospyros lotus, Halesia*
PFT 25 : Broadleaved raingreen tropical trees	*Adansonia, Bursera, Dendropanax, Gironniera, Bombax*
PFT 26 : Broadleaved evergreen tropical trees	*Annona, Bombax, Bursera, Cupania, Monotes, Sterculia, Zenkerella*

Main taxa list used to define each PFT

Plant Functional Types (PFTs)

- *photosynthesis & growth calculated for all PFTs*
- *stress/germination parameters evaluated from present-day distribution*
- *competition between PFTs to fill gaps produced by natural or stress-induced mortality*

European Classification (BAGs)

1. Achillea, Alchemilla, Angelica, Campanula
2. Brassicaceae, Caltha, Cardamine, etc
3. Anthemis, Artemisia, Bidens, Calystegia, etc
4. Asteraceae asteroideae, Poaceae, etc
5. Anemone, Gypsophila, Helleborus, etc
6. Ephedra, Ulex
7. Alnus vir, Arctostap., A.alpinus, B. nana
8. Sambucus, Frangula a, Prunus, Sorbus, Vaccinium
9. Berberis vul., Crataegus, Genista, Rhamnus
10. Artostaphylos uva-ursi, Calluna vul., Daphne
11. Buxus sempervirens, Hedera h., Ilex acquif.
12. Cistus, Myrtus
13. Betula, Salix
14. Alnus, A gl, Corylus, Q. robur, Populus, Tilia
15. Acer, Fraxinus, F excel, Tilia cordata, Ulmus
16. Acer campestre, Carpinus, Fagus syl, Tilia platyphyllos
17. Castanea, Juglans, Ostrya, Q. pubescens
18. Olea eur, Pistacia, Phillyrea, Q ilex, Q suber
19. Larix decidua
20. Picea abies, Pinus, Pinus sylvestris
21. Abies
22. Cupressaceae, Juniperus, Juniperus communis
23. Pinus Cembra
24. Abies Alba, Taxus
25. Cedrus, Pinus halepensis, Pinus pinaster

Overstorey

Trees

Global PFTs 12 – 26

Competition: $N^i_{seeds} = \alpha\ p^i_{germ}.NPP_i$
(seeds fill gaps left by motality)

Understorey

Herbs

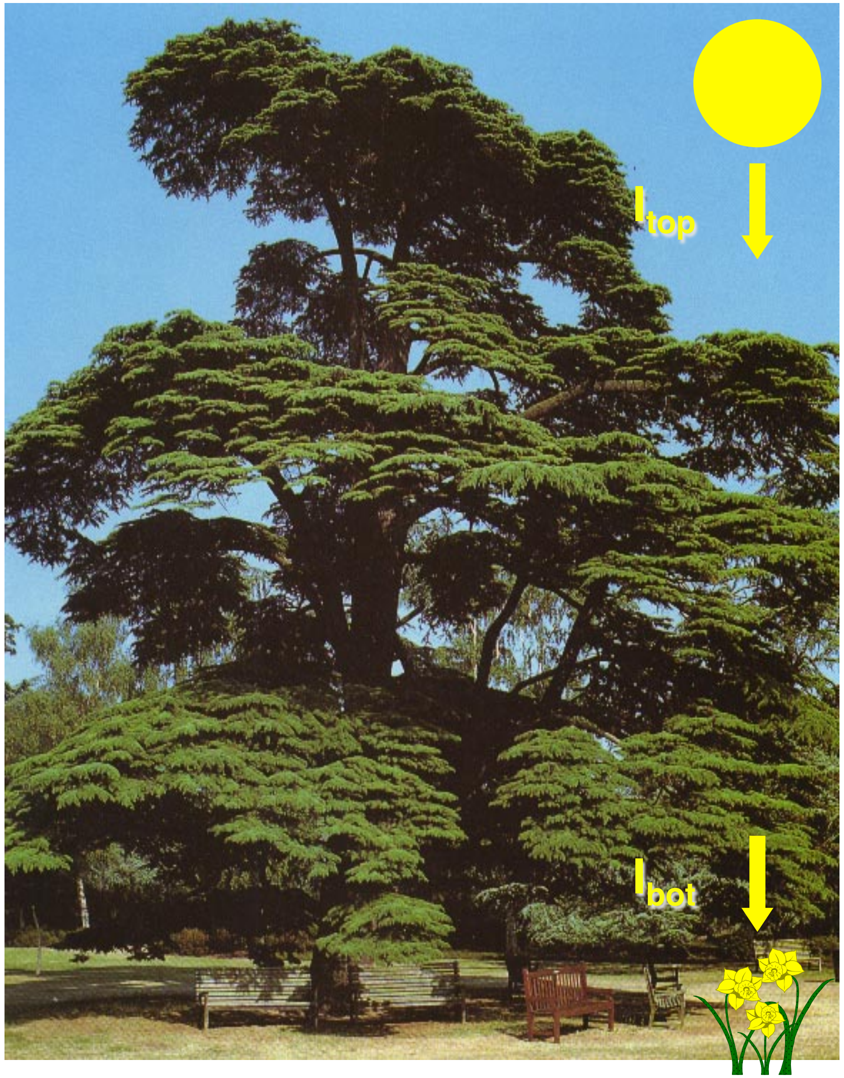
Global PFTs 1 – 3

Shrubs

Global PFTs 4 – 11

Competition: $N^i_{seeds} = \alpha\ p^i_{germ}.NPP_i$
(seeds fill gaps left by motality)

COMPETITION OF PLANT FUNCTIONAL TYPES



Response to stress and mortality

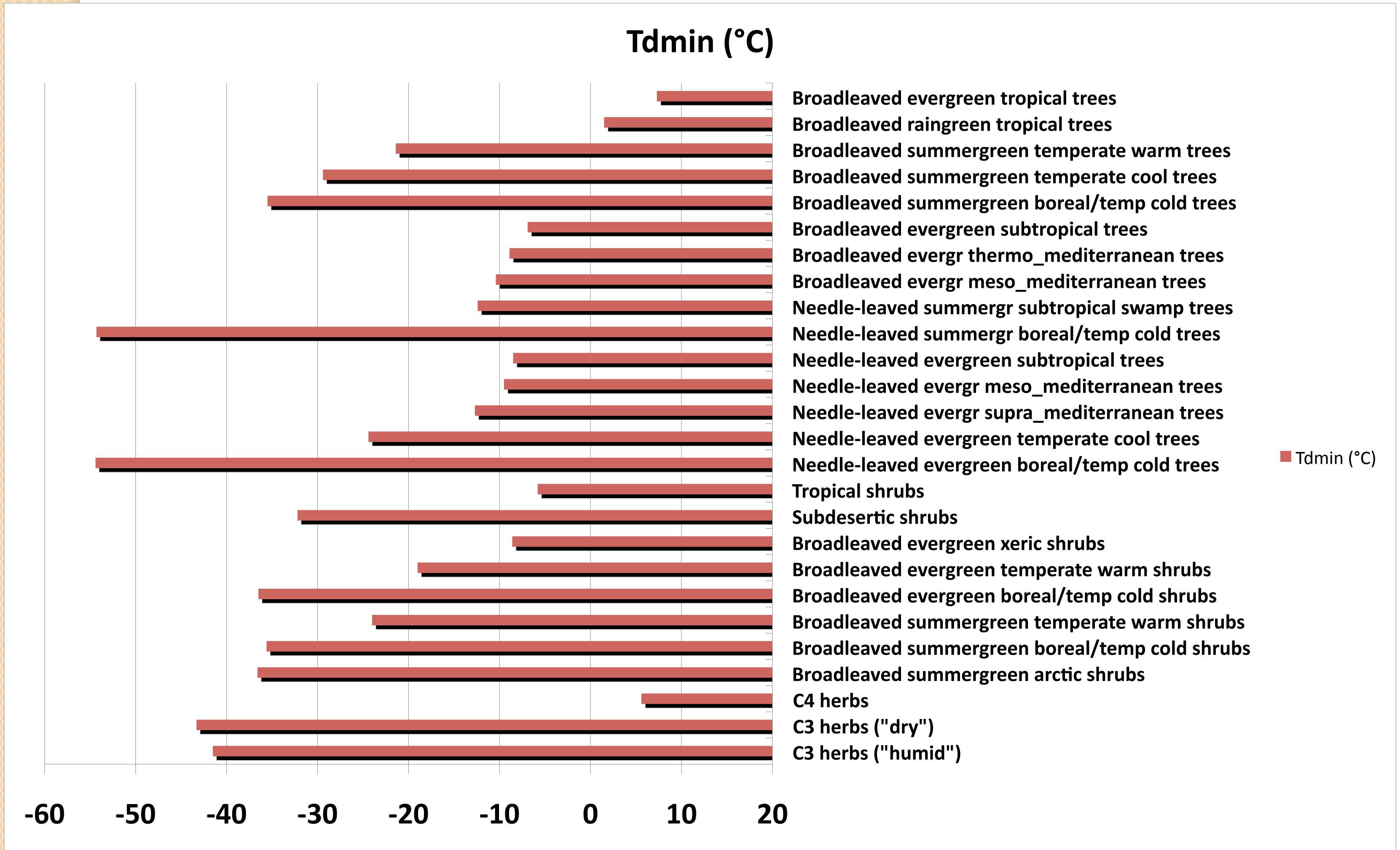
Temperature (T) stress

- effects on growth through change in **photosynthesis** and autotrophic **respiration**
- **mortality** occurs at **cold temperatures** (T<Tdmin)

Soil water (SW) stress

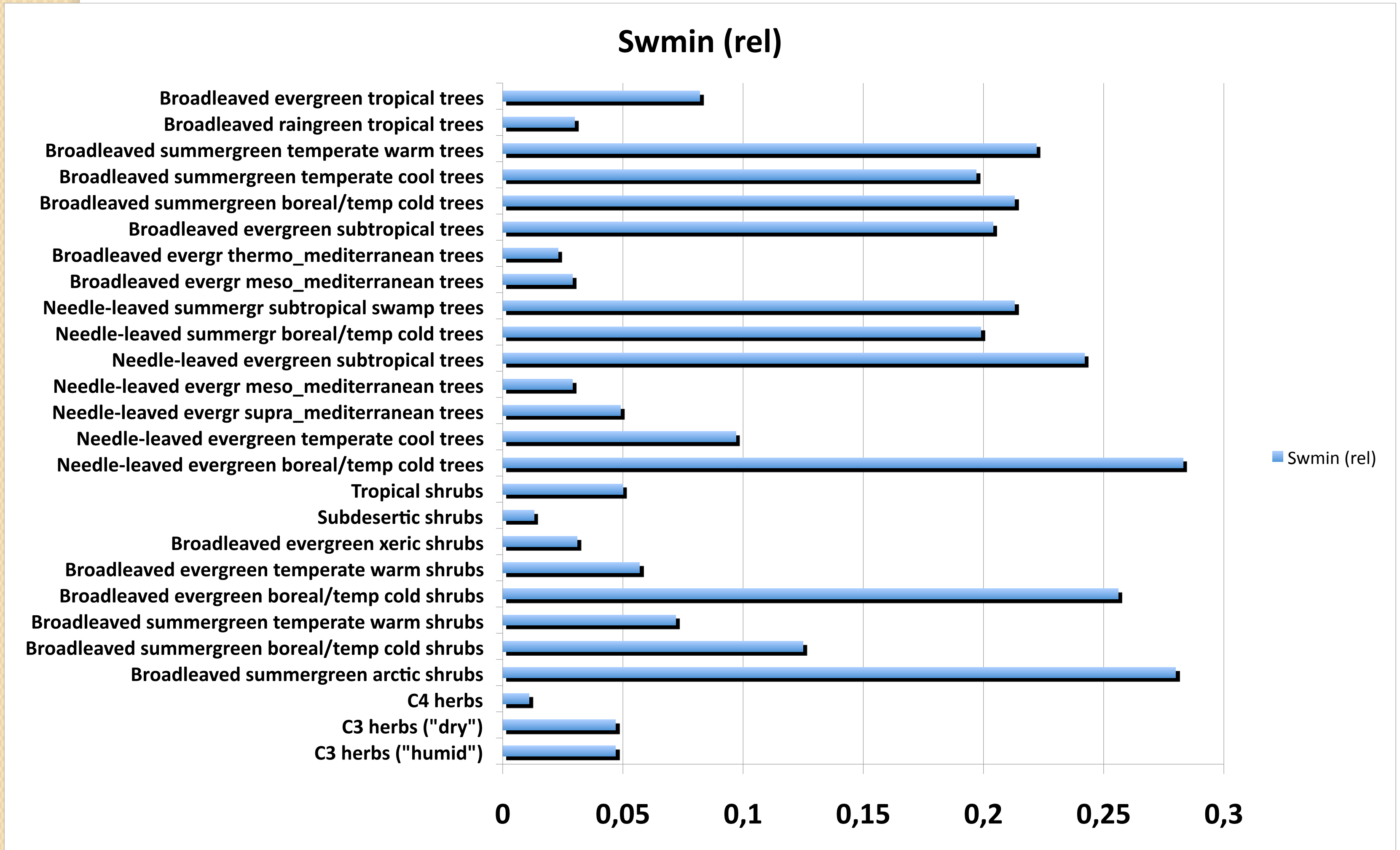
- reduced growth through **stomatal resistance**
- **leaf fall** if **evaporation** is too large with respect to the amount of water that can be taken from the soil
- **mortality** occurs under critical soil water (SW<SWmin)
- **fires** can burn some part of the pixel at low SW

Temperature stress : Tdmin



Quantile: 1% (C3 grasses), 5% (other PFTs)

Soil water stress : SWmin



Quantile: 10% (all PFTs)

Germination

In the standard version of CARAIB (without seed dispersal), germination is assumed to occur for each PFT on any grid cell when the following criteria are met (full dispersion):

Temperature of the coldest month (T_c)

➔ need of cold winter: $T_c < T_{max,germ}$

Growing degree days above 5°C (GDD5)

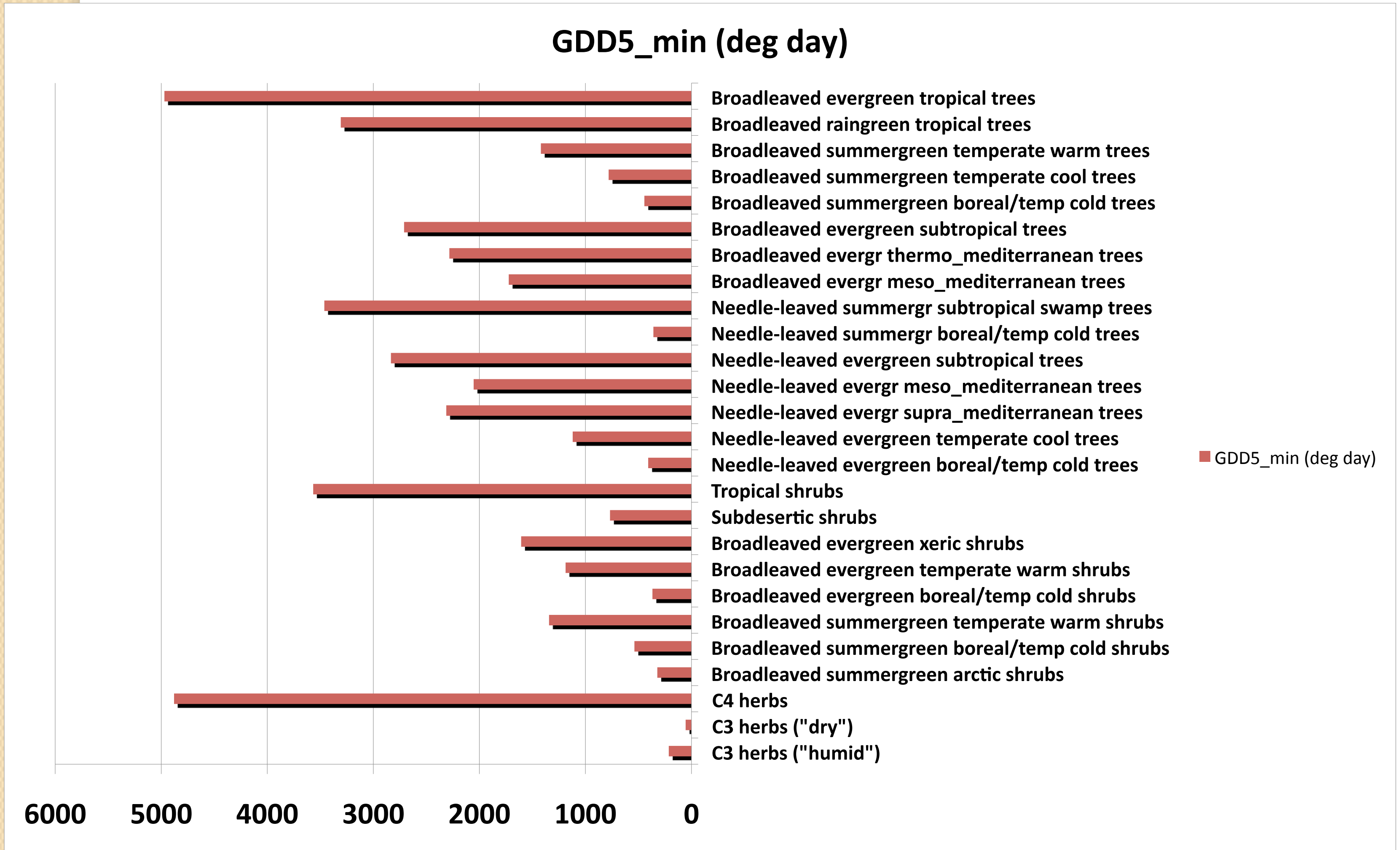
➔ need of long enough vegetation season: $GDD5 > GDD5_{min}$

Soil water of the driest month (SW_d)

➔ need of dry period: $SW_d < SW_{max}$

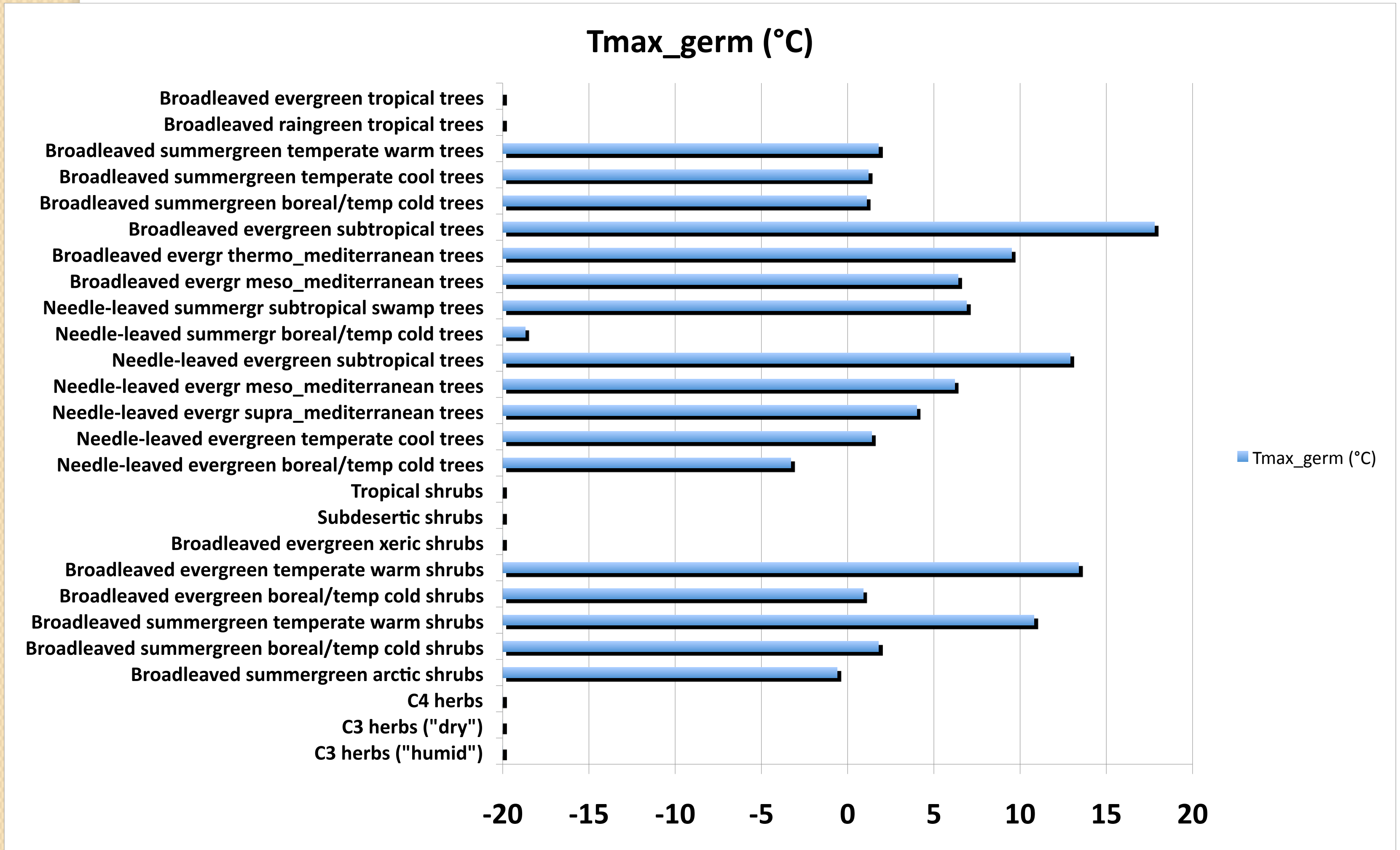
(for Mediterranean BAGs)

Germination requirements : GDD5



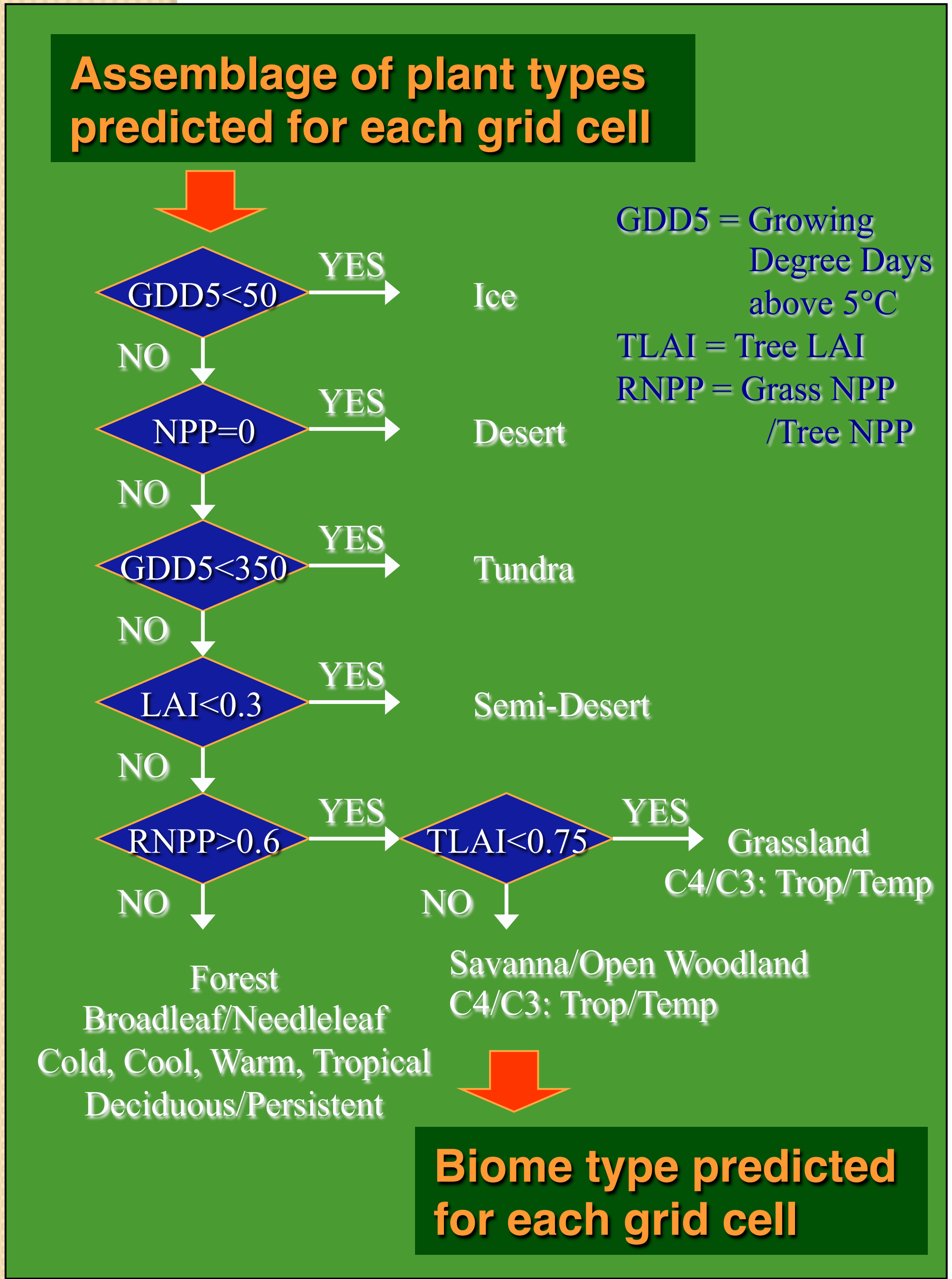
Quantile: 1% (C3 grasses), 5% (other PFTs)

Germination requirements : Tmax_germ



Quantile: 10% (all PFTs)

BIOMES



Assemblage of plant types predicted for each grid cell
GDD5<50
YES
Ice
NO
NPP=0
YES
Desert
NO
GDD5<350
YES
Tundra
NO
LAI<0.3
YES
Semi-Desert
NO
RNPP>0.6
YES
TLAI<0.75
YES
Grassland
C4/C3: Trop/Temp
NO
NO
Forest
Broadleaf/Needleleaf
Cold, Cool, Warm, Tropical
Deciduous/Persistent
Savanna/Open Woodland
C4/C3: Trop/Temp
GDD5 = Growing Degree Days above 5°C
TLAI = Tree LAI
RNPP = Grass NPP /Tree NPP
Biome type predicted for each grid cell

Boreal/montane forest
Cool temperate mixed forest
Cool temperate conifer forest
Temperate broadleaved deciduous forest
Warm temperate mixed forest
Warm temperate conifer forest
Warm temperate broadleaved evergreen forest
Sub-tropical forest
Tropical seasonal forest
Tropical rainforest
Cold temperate/boreal open woodland
Warm temperate open woodland (Mediterranean)
Tropical savanna
Temperate grassland
Tropical grassland
Tundra
Semi-desert
Desert
Ice

Main model inputs

- ❑ Climatic data (monthly → diurnal: stochastic generator)
  - Air temperature (T_{min}, T_{max})
  - Precipitation
  - Sunshine hours (cloudiness) / Solar flux
  - Air relative humidity
  - Wind speed

  Present-day: CRU climatology
  Past/Future: GCM anomalies combined with present-day climatology

- ❑ Soil data
  - texture (%sand, %silt, %clay)
  - soil colour (dark to bright)

- ❑ Elevation (→ average pressure)

Main model PFT/species parameters

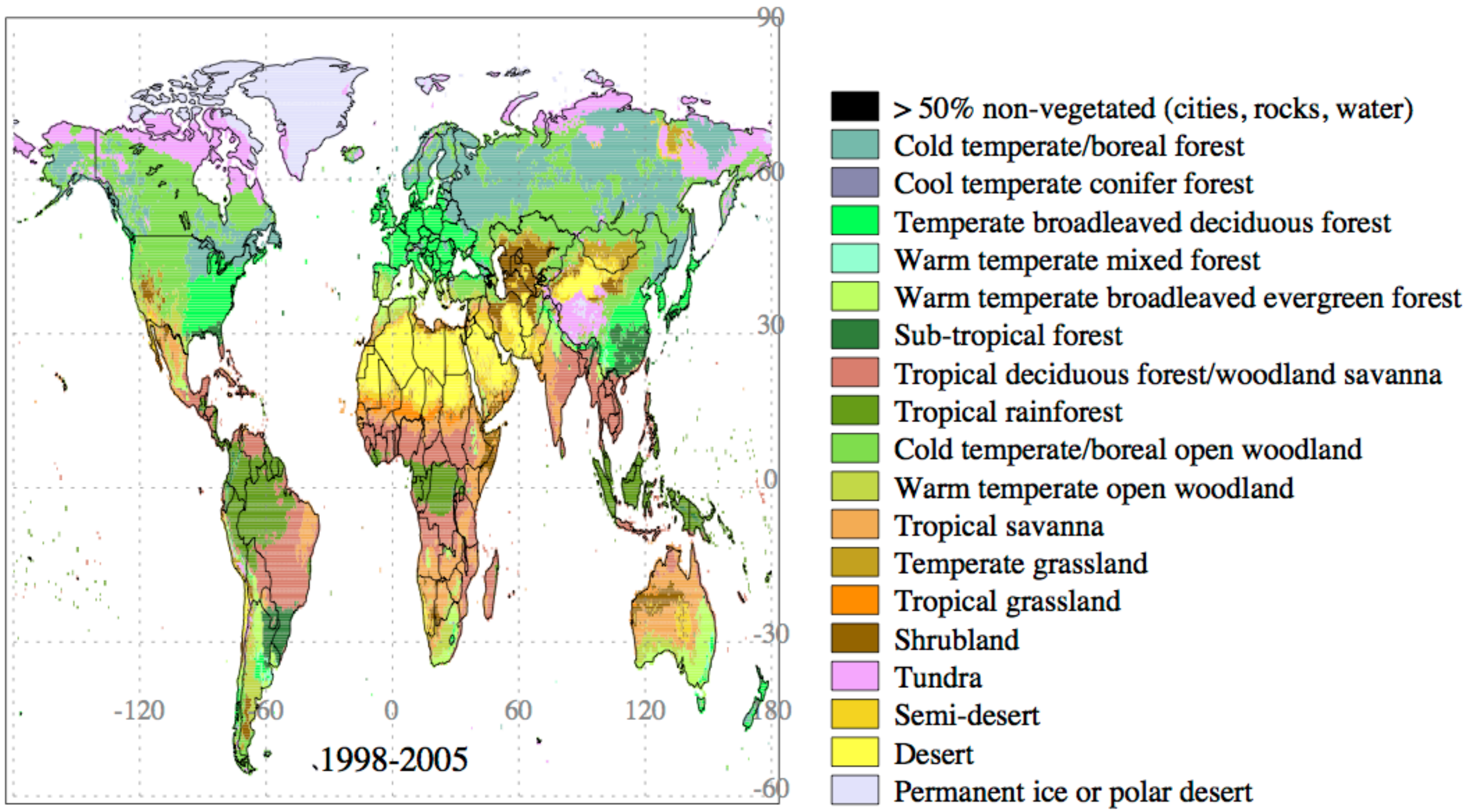
- Climatic thresholds
  - Stress conditions: Tmin, SWmin
  - Germination requirements: GDD5min, Tmax_germ, SWmax_germ
  - Phenology: Temp, SW for bud burst or leaf fall
- Aerodynamic and hydrological parameters
  - roughness length, displacement height (-> tree height)
  - root depth
- Photosynthesis and respiration
  - specific leaf area
  - leaf and wood C:N ratios
  - stomatal resistance parameters
- Reservoir turnover times
  - leaf/wood turnover (background value, under T stress, under SW stress)
  - litter/soil organic C turnover

Standard model outputs

- Soil hydrology (monthly)
  - Reservoirs: soil water amount, snow depth
  - Fluxes: PET, AET, RUNOFF (surf, deep drainage), snow melt/evap
- Surface energy budget (monthly)
  - albedo
  - surface soil temperature
  - latent and sensible heat exchanges
  - solar radiation / downward IR / net radiation
- Vegetation (monthly)
  - GPP, NPP, NEP, LAI
- Vegetation (annual per plant type)
  - NPP, GPP, LAI
  - biomass, soil carbon
  - burned area, probability of fire
  - ^{13}C discrimination

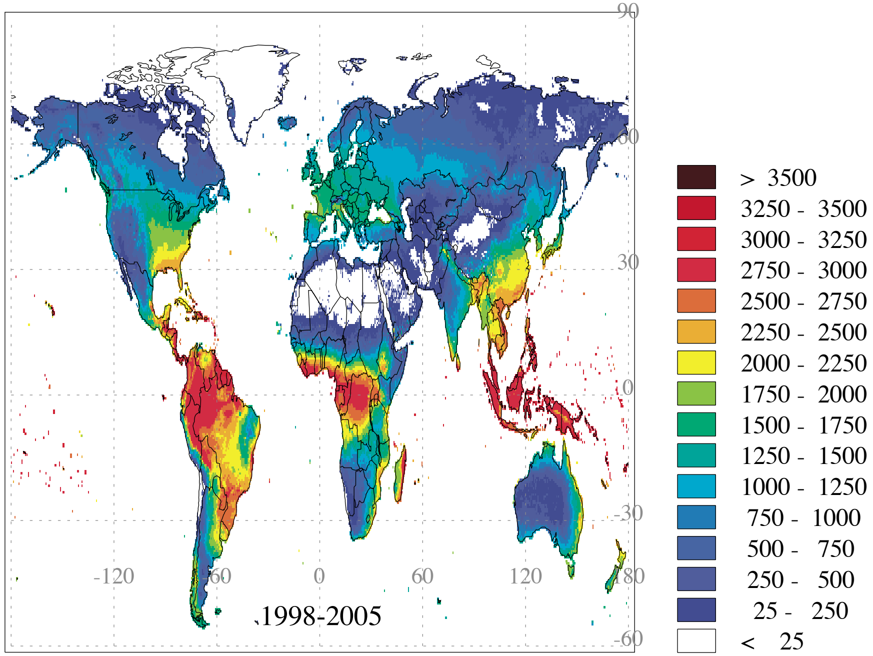
Examples of Results and Model Validation

Biome Distribution

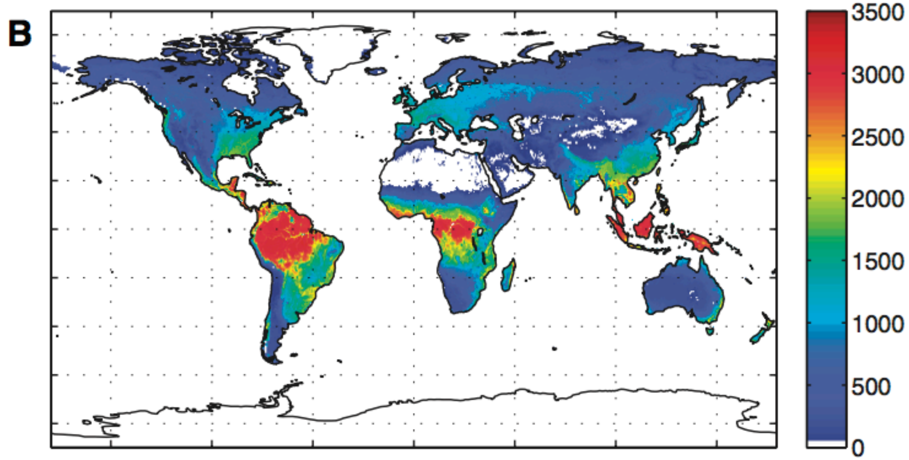


Mean 1998-2005 annual Gross Primary Productivity (g C m^{-2} yr^{-1})

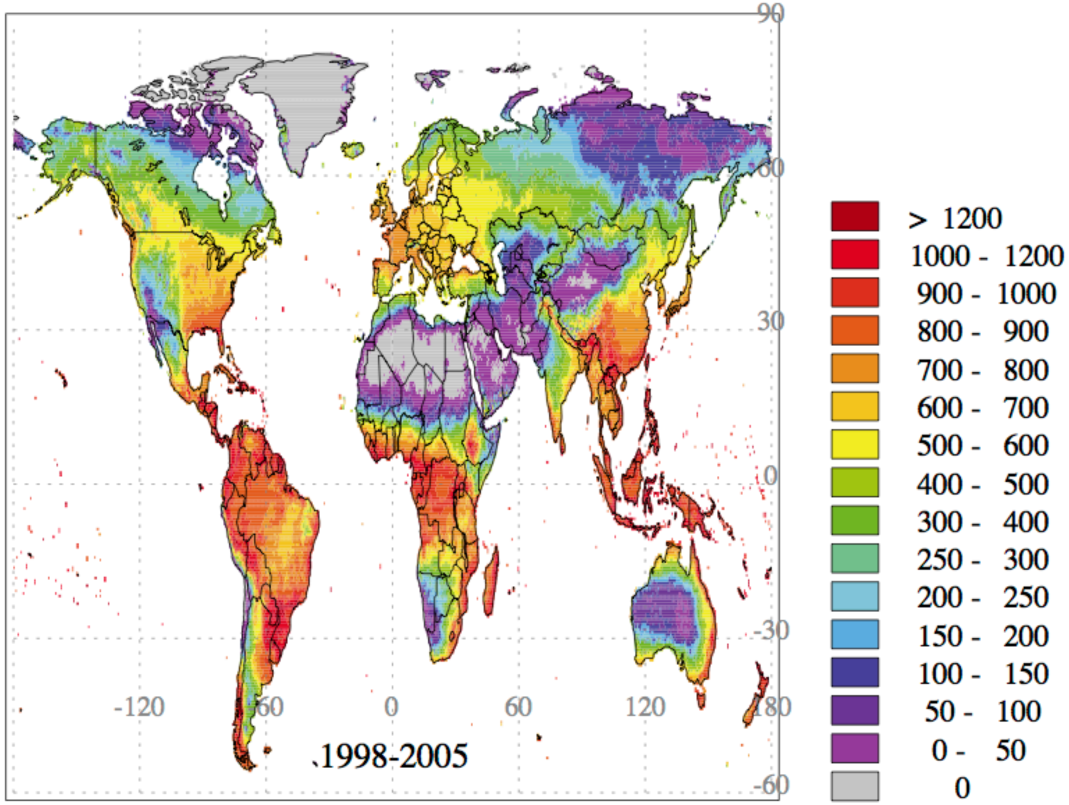
CARAIB



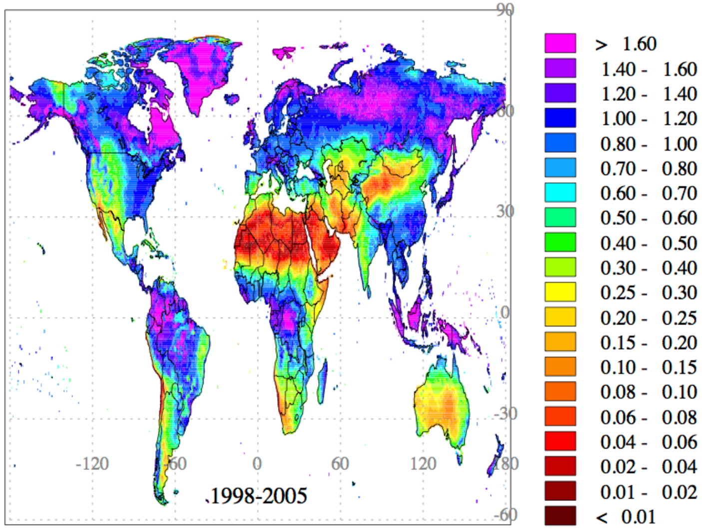
Beer et al. (2010) (data-based)



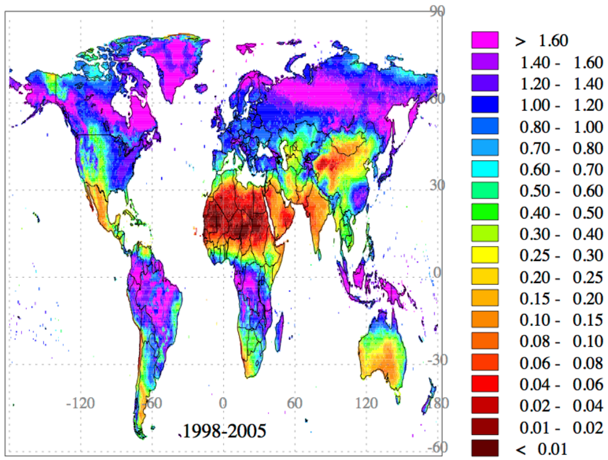
NPP ($g\ C\ m^{-2}\ yr^{-1}$) [Annual]



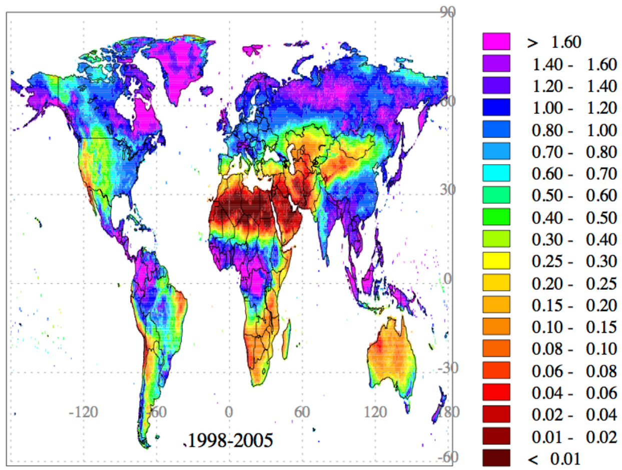
Soil Water (SW-WP)/(FC-WP) [Annual Mean]



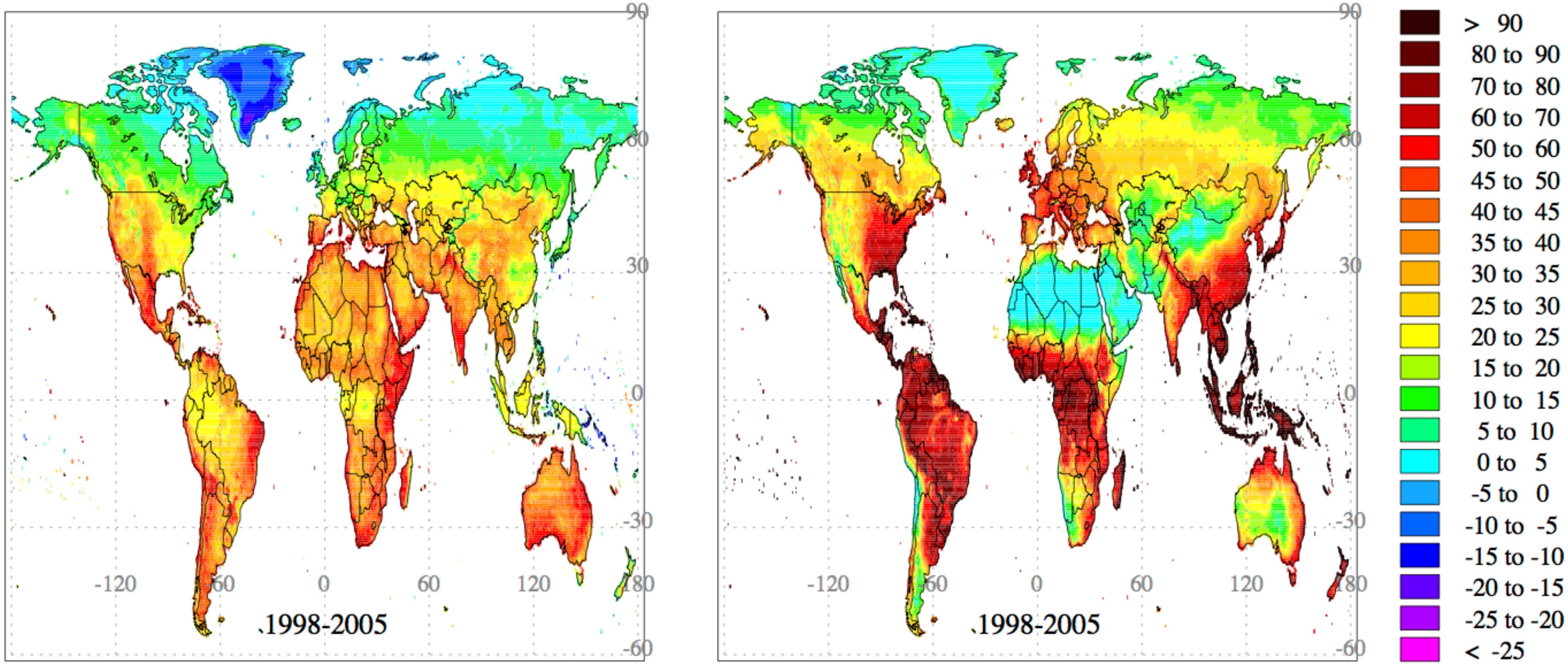
Soil Water (SW-WP)/(FC-WP) [MAM]



Soil Water (SW-WP)/(FC-WP) [SON]

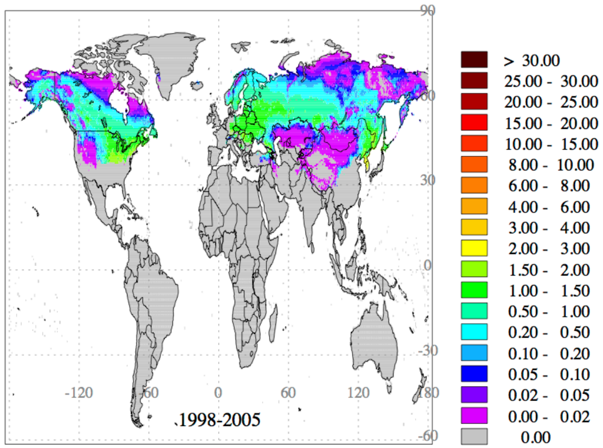


Sensible Heat Flux (W m^{-2}) [Annual Mean]   Latent Heat Flux (W m^{-2}) [Annual Mean]

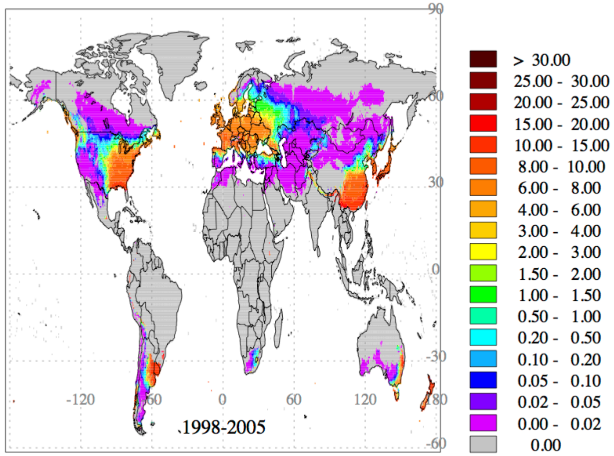


DISTRIBUTION OF PLANT FUNCTIONAL TYPES

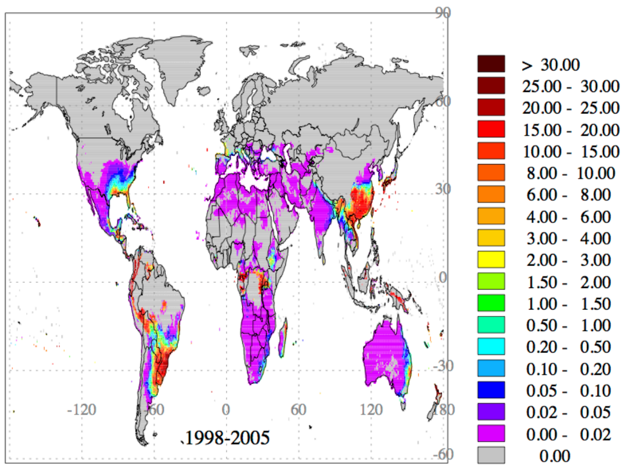
PFT Biomass (kg C m^{-2})
[17 Needleleaved summergr boreal/temp cold trees]



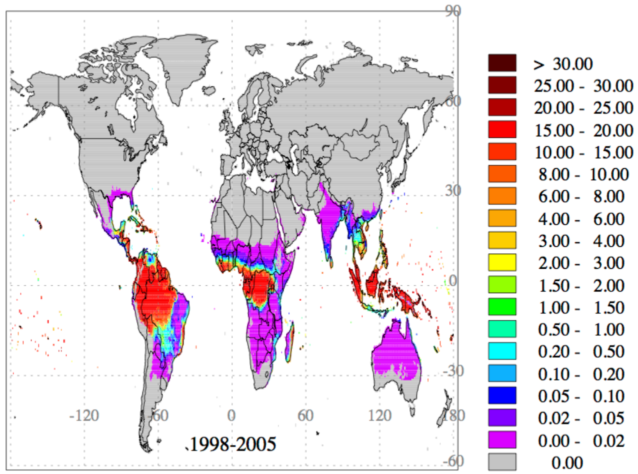
PFT Biomass (kg C m^{-2})
[23 Broadleaved summergreen temperate cool trees]



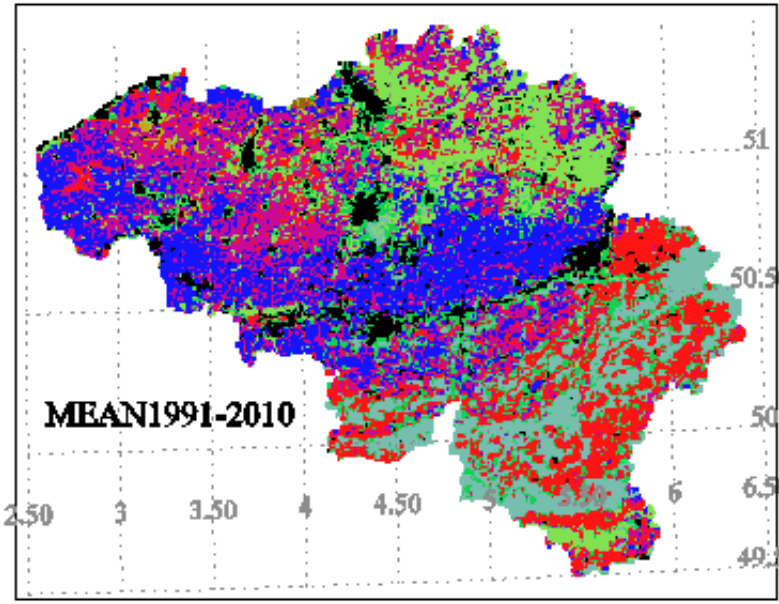
PFT Biomass (kg C m^{-2})
[21 Broadleaved evergr subtrop drought-int trees]

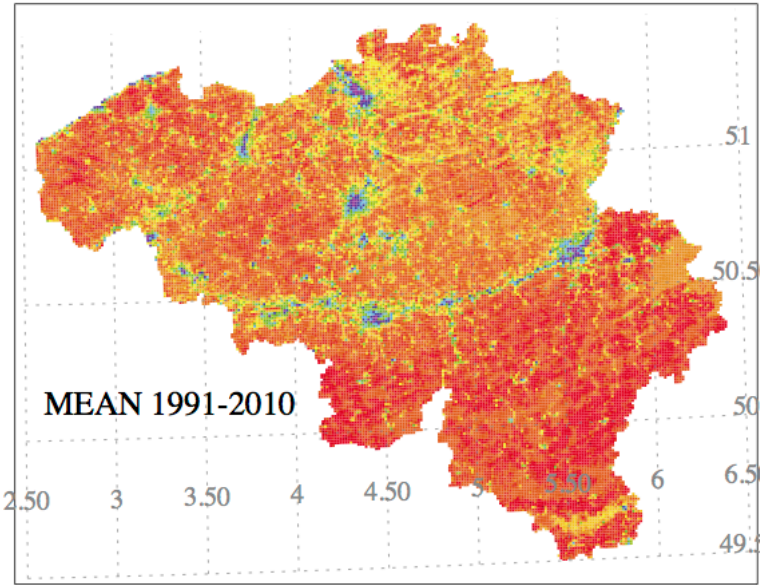


PFT Biomass (kg C m^{-2})
[26 Broadleaved evergreen tropical trees]



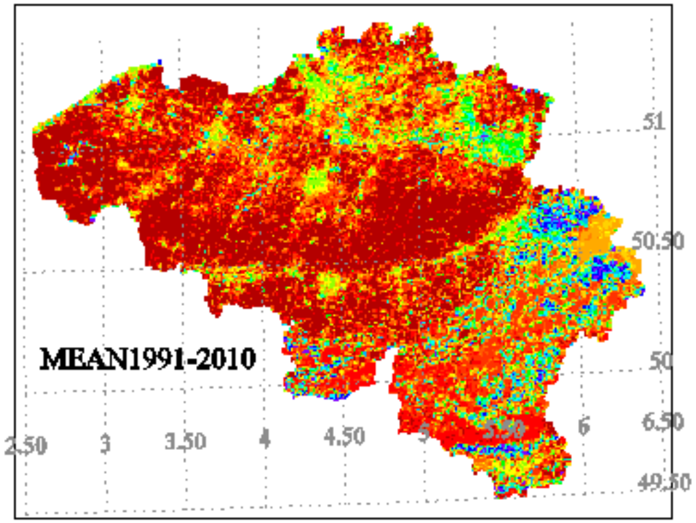
SIMULATIONS WITH LAND USE OVER BELGIUM (1 km^2)



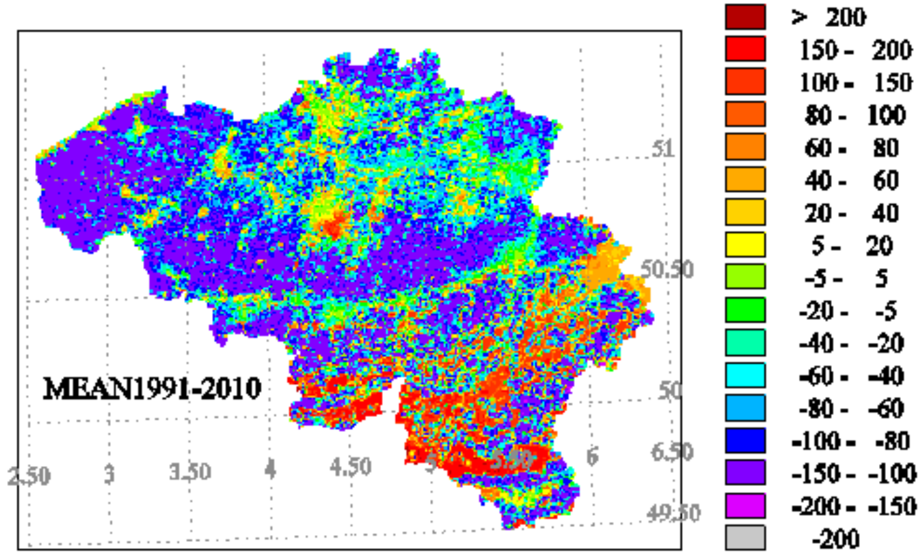


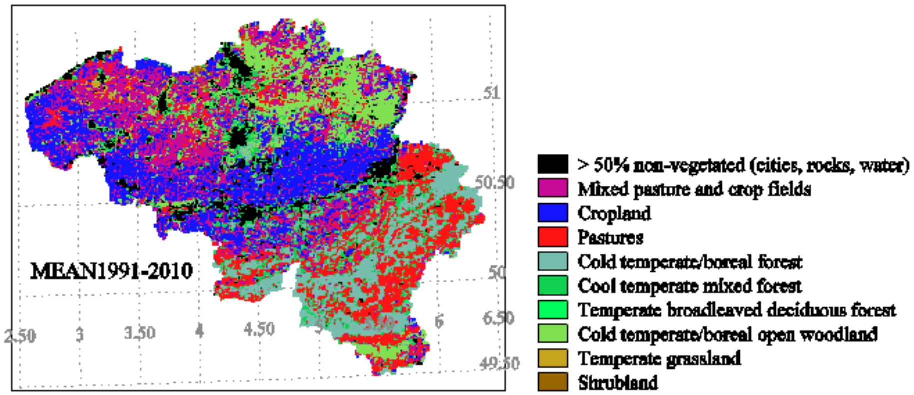
MASC
LAND USE-CLIMATE
INTERACTIONS

Net Ecosystem Productivity
(g C m^{-2} yr^{-1})



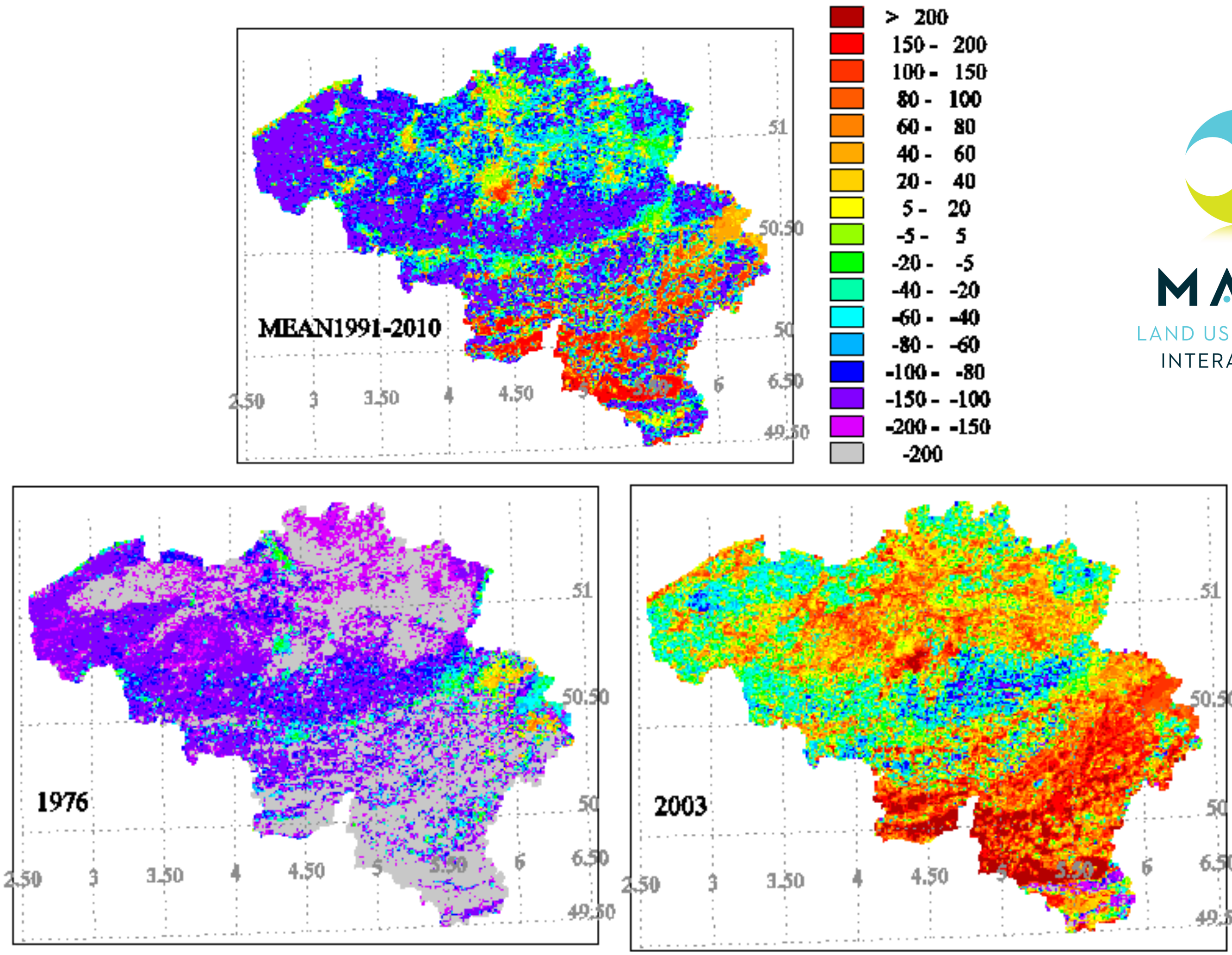
Net Biome Productivity
(g C m^{-2} yr^{-1})





MASC
LAND USE-CLIMATE
INTERACTIONS

Net Biome Productivity
(g C m^{-2} yr^{-1})



MASC
LAND USE-CLIMATE
INTERACTIONS

ISMIP2a intercomparison

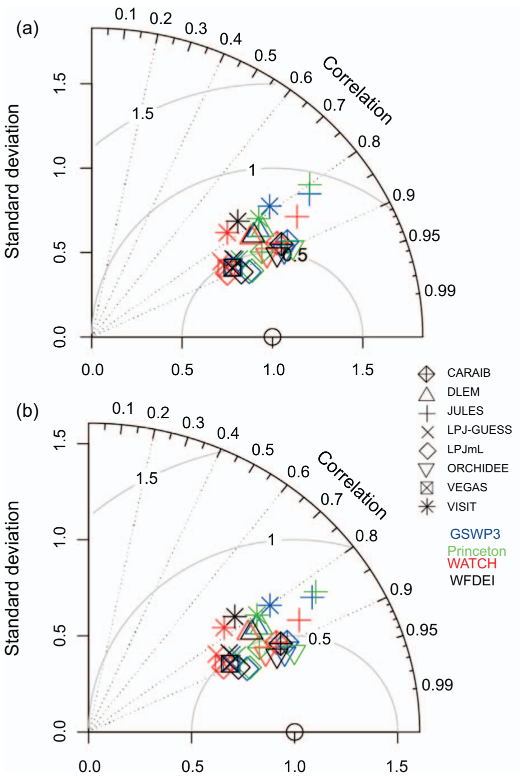


Figure 3. Taylor diagrams of annual gross primary production (GPP) simulated by eight biome models using four meteorological forcing datasets relative to (*a*) MODIS GPP and (*b*) flux up-scaled GPP. The correlation and standard deviation were calculated for the period 2000–2010 for the GSWP3, Princeton, and WFDEI cases. In the WATCH cases, the simulated GPP in 1990–2000 was used due to the limitation of the simulation length.

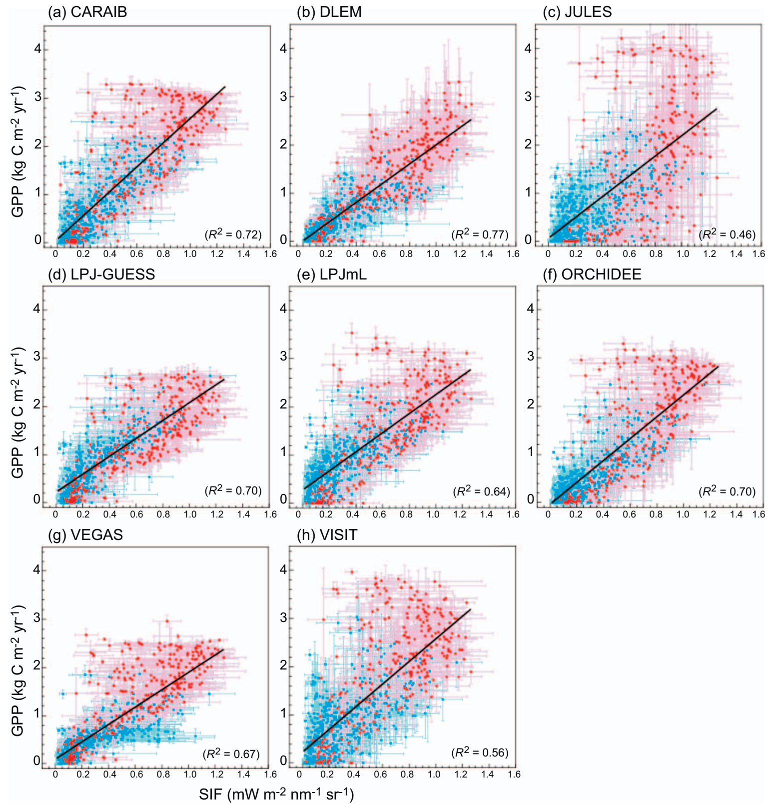
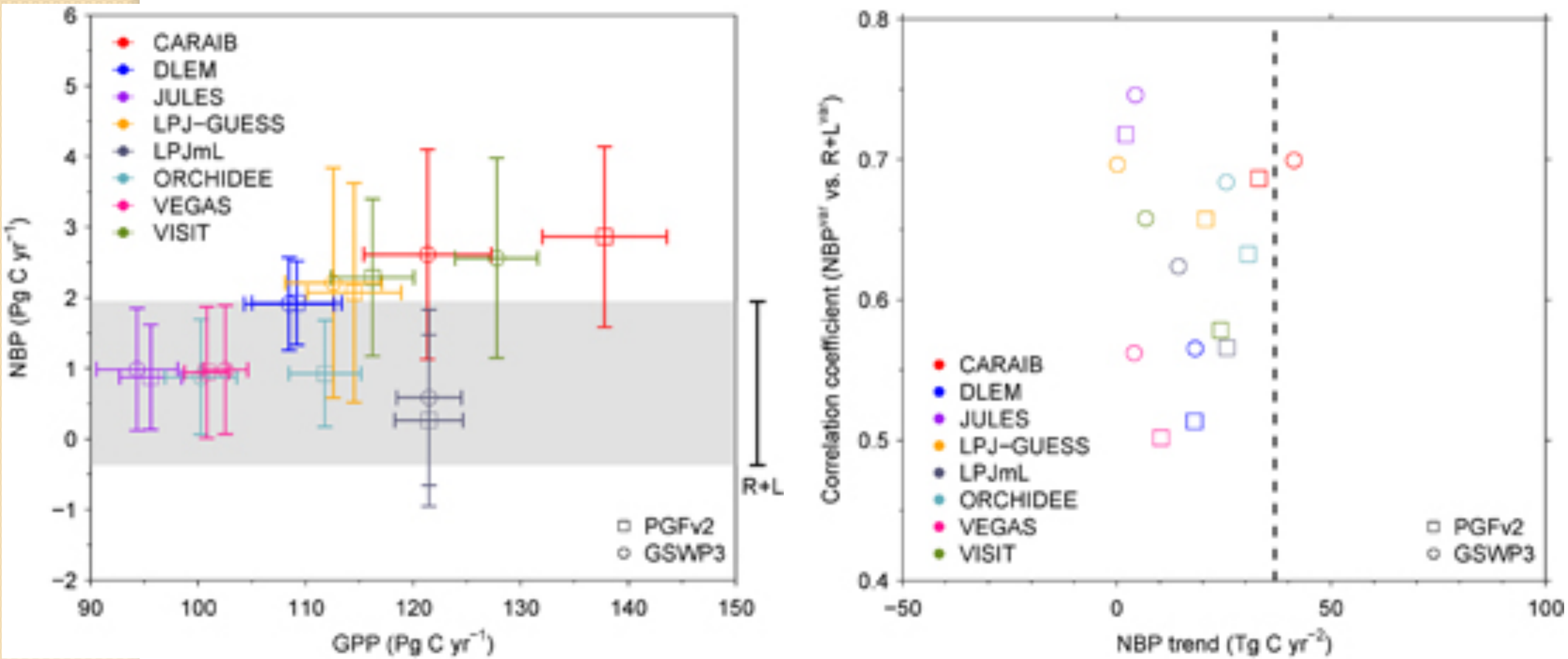


Figure 4. Global relationship between sun-induced chlorophyll fluorescence (SIF) from GOME-2 and gross primary production (GPP) simulated by the eight biome models (*a–h*), during the period 2007–2010 using the GSWP3 forcing dataset. Black lines show linear regression (R^2 in parentheses). Both SIF and GPP data were aggregated into 5°-mesh to reduce the influence of observational noise; bars show the standard deviation within the 5°-grids. Red dots show tropical areas (25°N–25°S), and blue dots show temperate and borealareas.

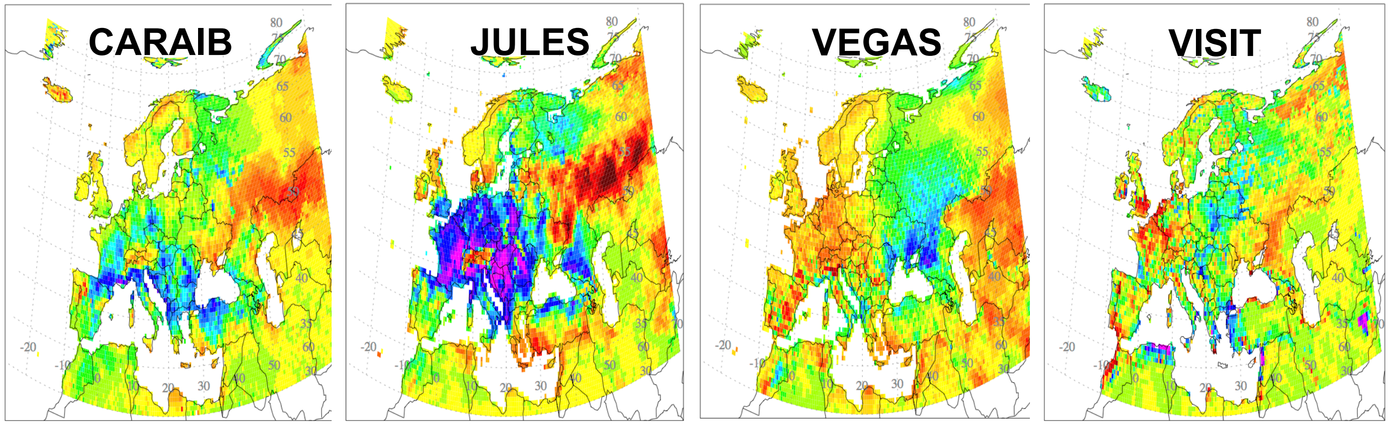
Ito et al. (2017)

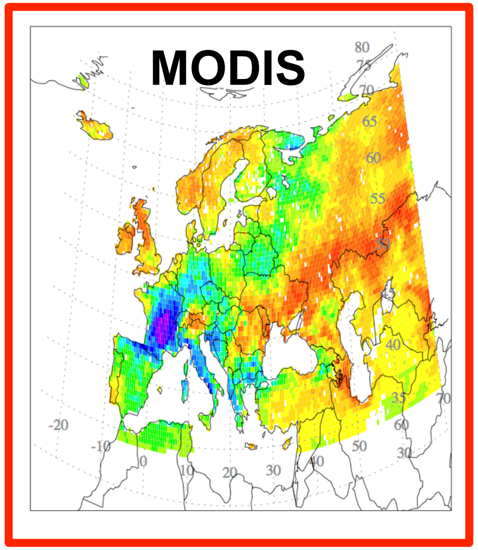


Chang et al. (2017)

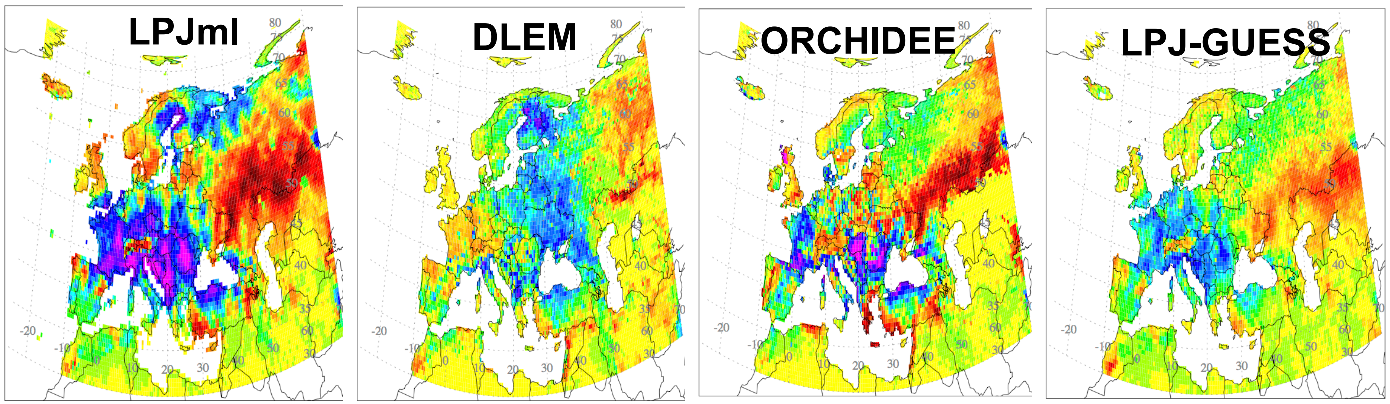
R+L = interannual variability in global Residual Land Sink (RLS) plus land use change emissions (ELUC) (R + L; Le Quéré et al 2015). Dashed line indicates the trend derived from R + L (Le Quéré et al 2015).

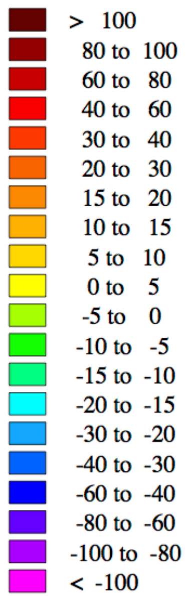
2003 Summer drought in Europe: Models vs MODIS





Gross Primary Productivity summer (JJA) anomaly
(reference period 2001-2010)
Princeton PGFv2 climatic data, « natural » simulations

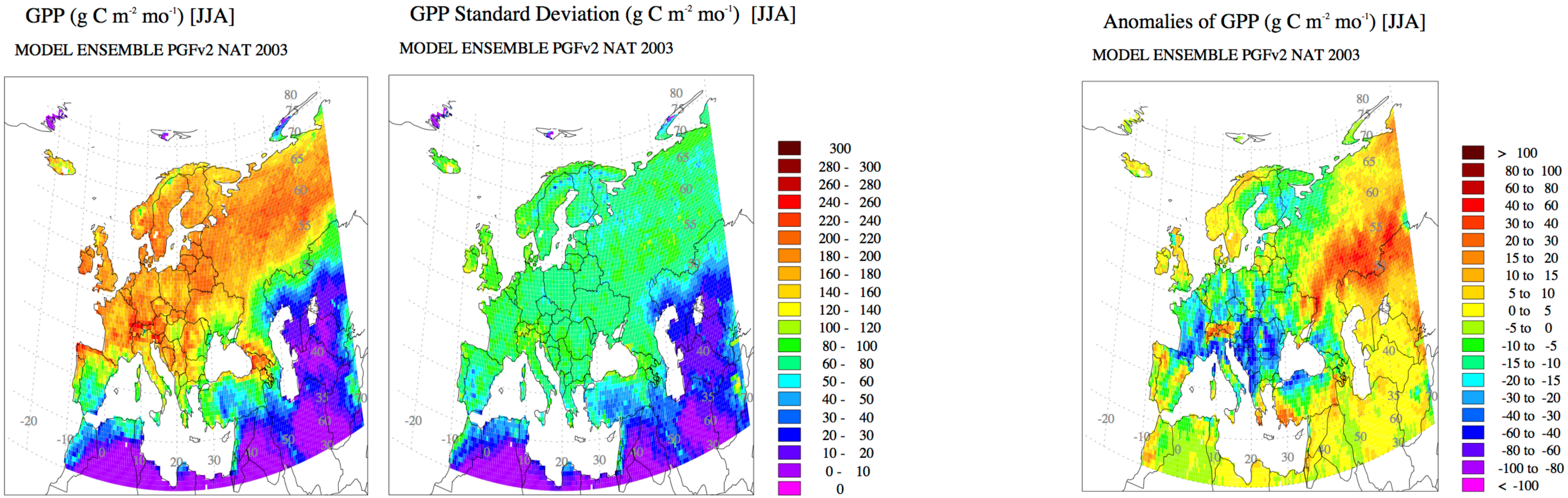


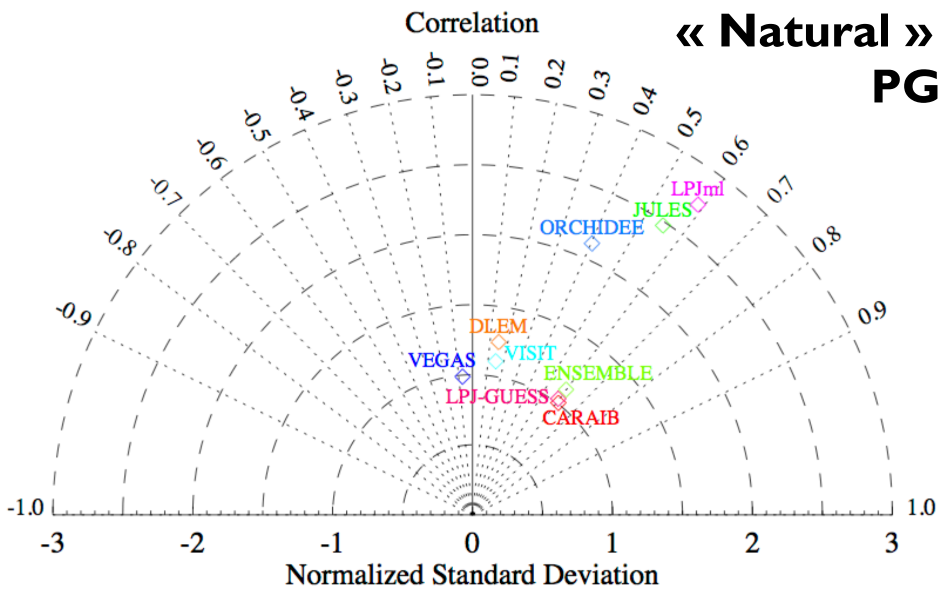


2003

(gC m^{-2} $month^{-1}$)

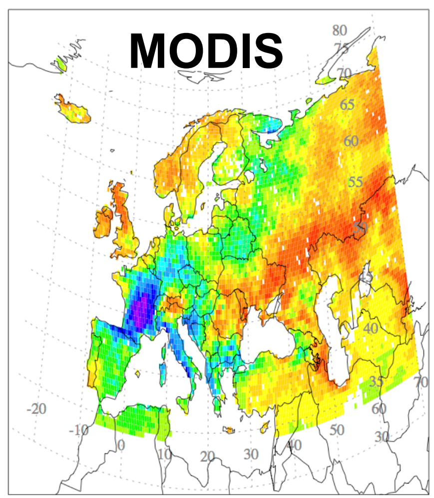
2003 Summer drought in Europe: Model ensemble



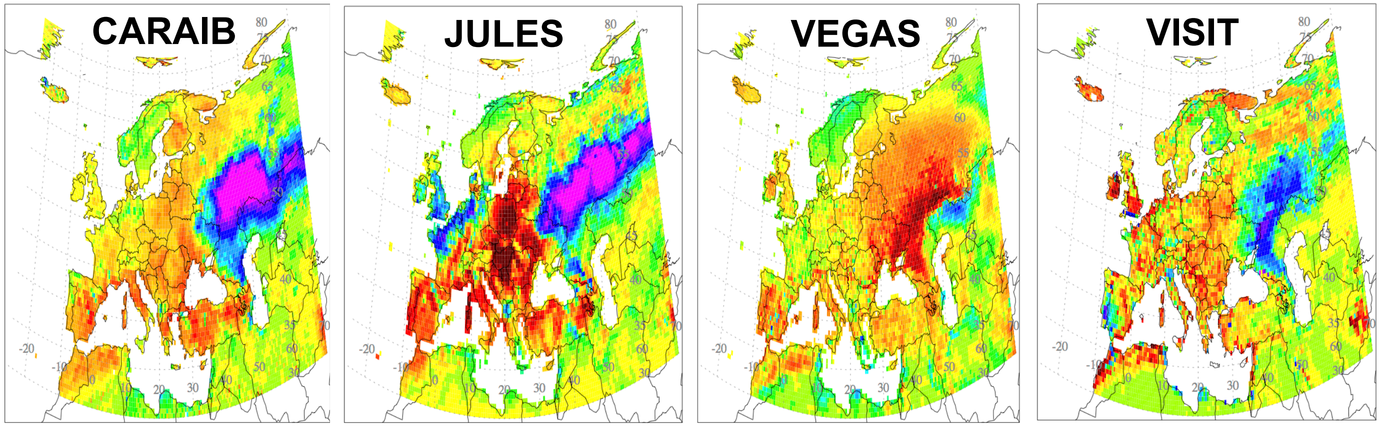


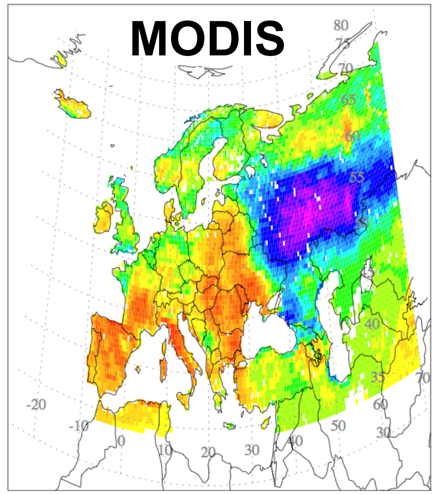
« Natural » simulations
PGFv2 climate

2003

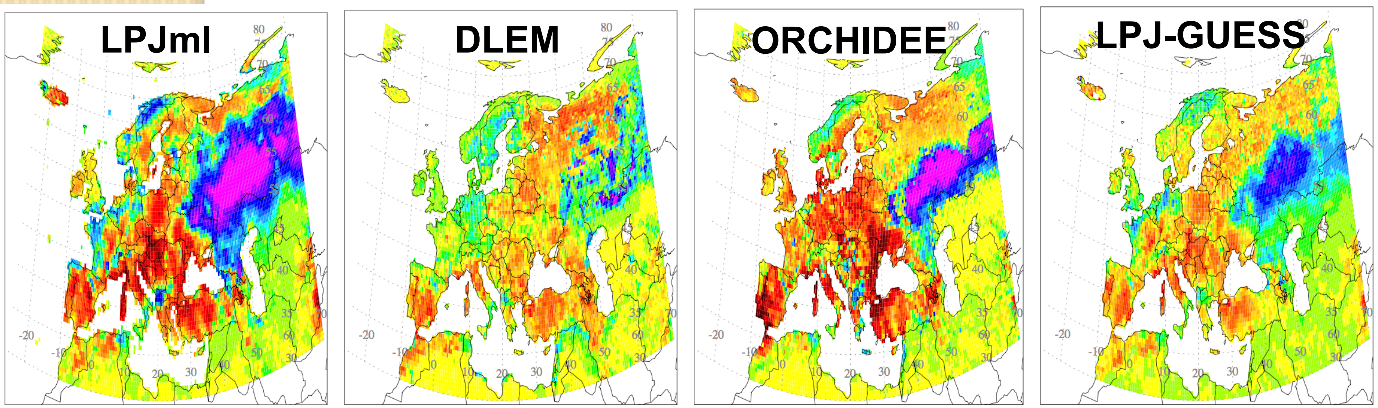


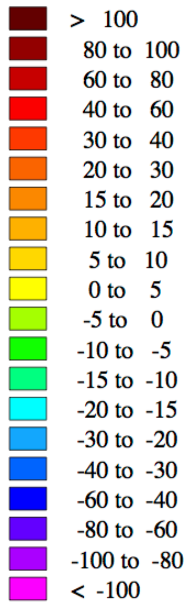
2010 Summer drought in Europe: Models vs MODIS





Gross Primary Productivity summer (JJA) anomaly
(reference period 2001-2010)
Princeton PGFv2 climatic data, « natural » simulations

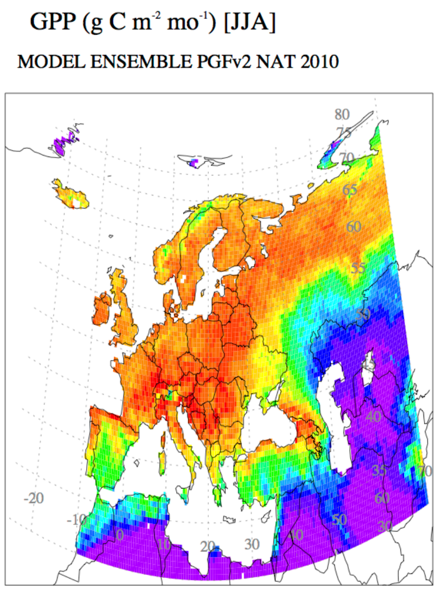


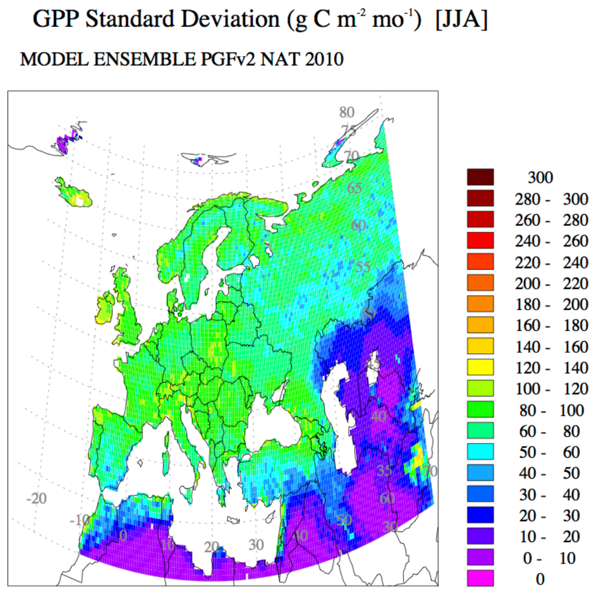


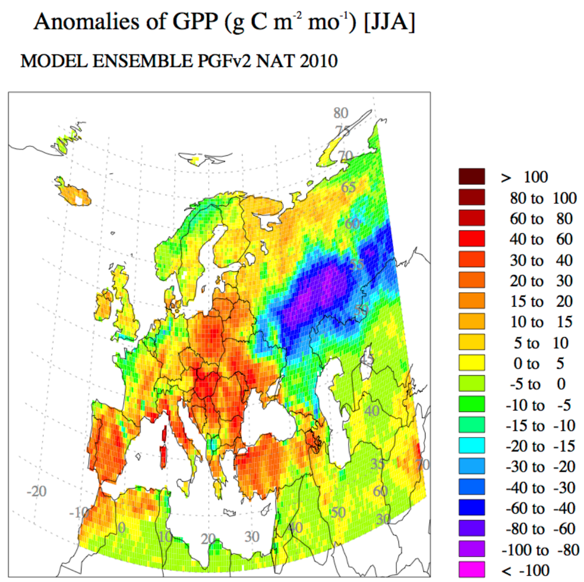
2010

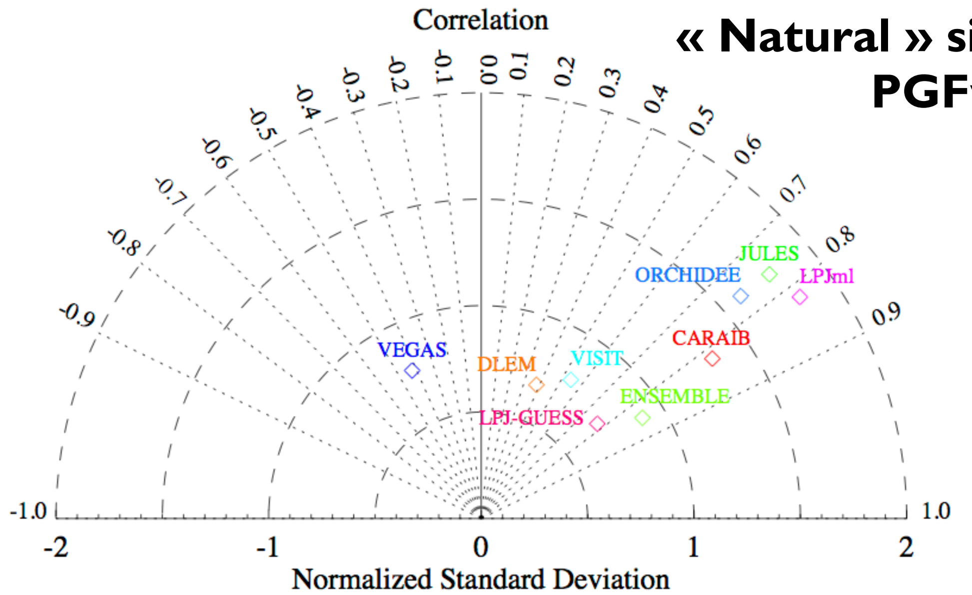
(gC m^{-2} $month^{-1}$)

2010 Summer drought in Europe: Model ensemble



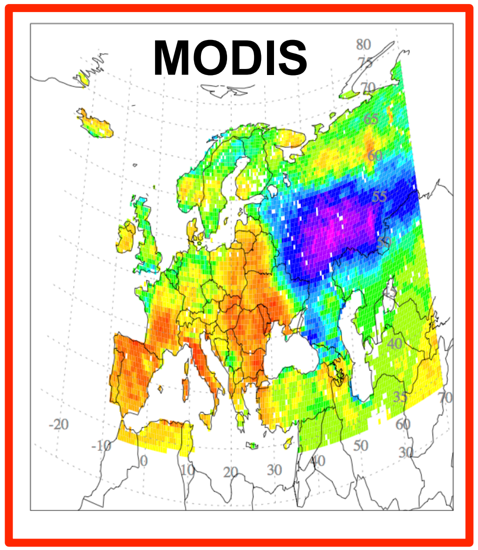






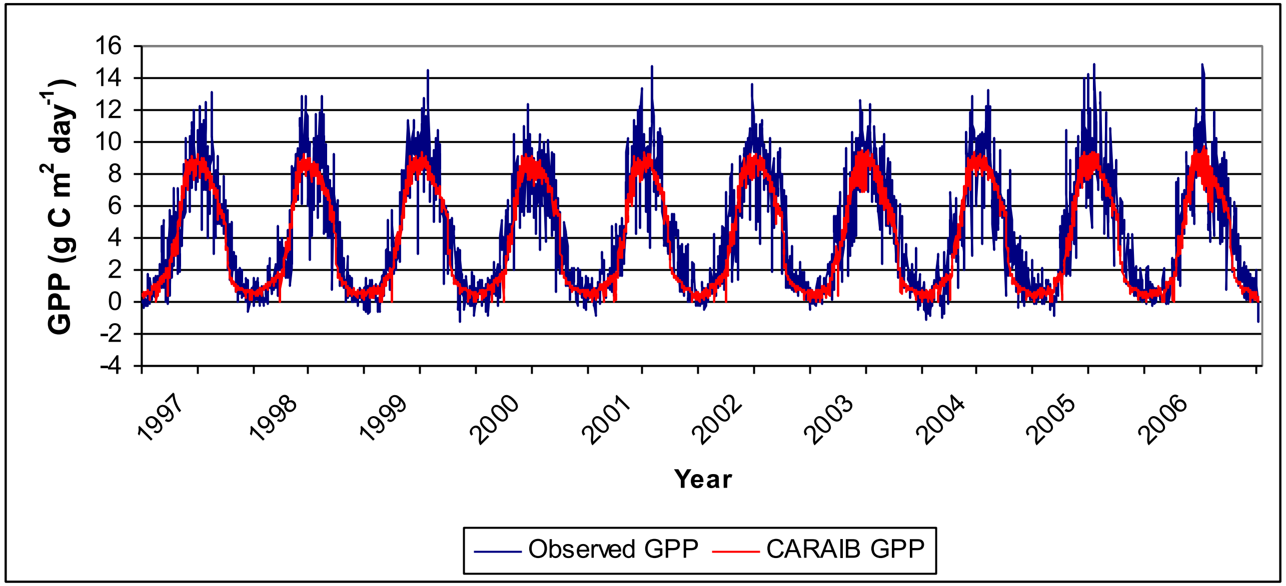
« Natural » simulations PGFv2 climate

2010



Site Level Simulations (GPP)

- Vielsalm, Belgium (CarboEuroflux site, 50°N, 6°E)
  mixed forest: *Fagus sylvatica, Pseudotsuga menziesii*
  - simulations with CRU monthly climatic data at 0.5°x0.5° (1997-2006)
  - model vegetation : BAG 16 + BAG 20 (European classification)
  - no specific adaptation of soil parameters to the site



Site Level Simulations

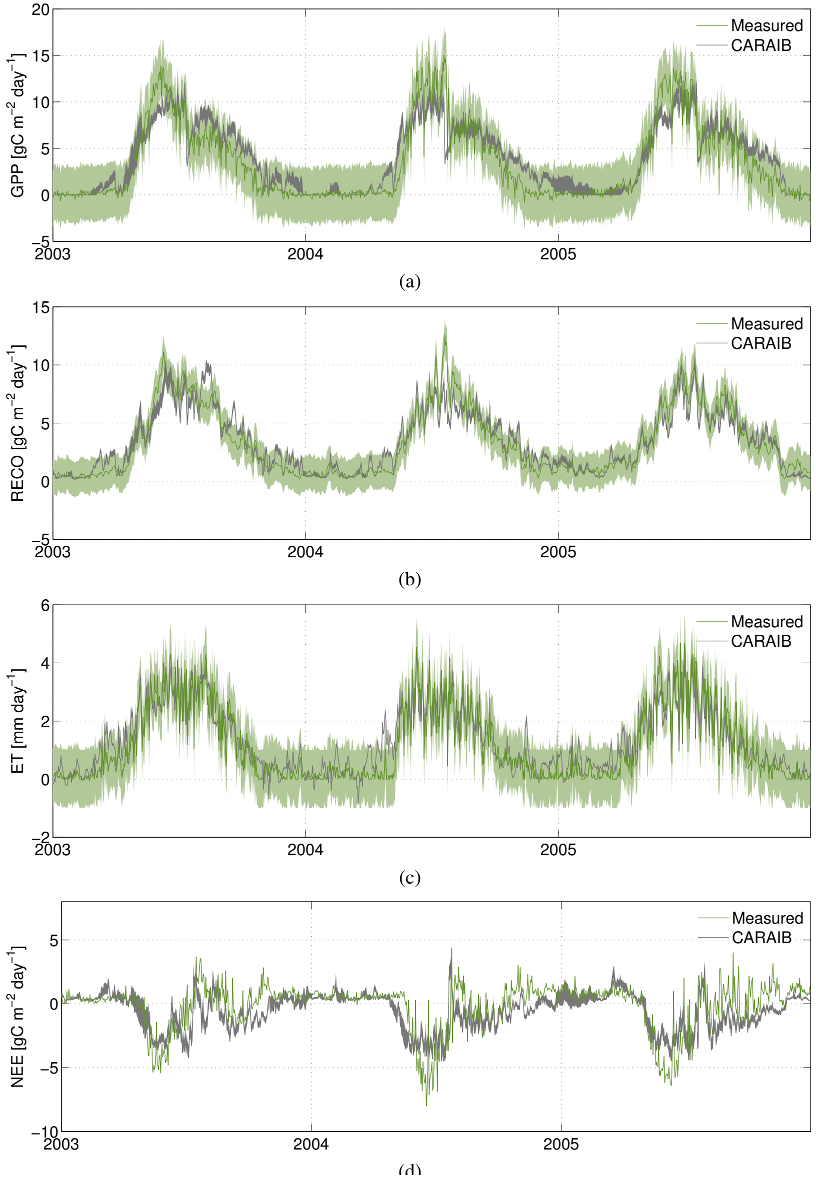
Monte Bondone (Italy) Grassland site.
Eddy covariance data with error bar (green) assimilated in the CARAIB model (1200 runs; grey)

GPP

Ecosystem Respiration

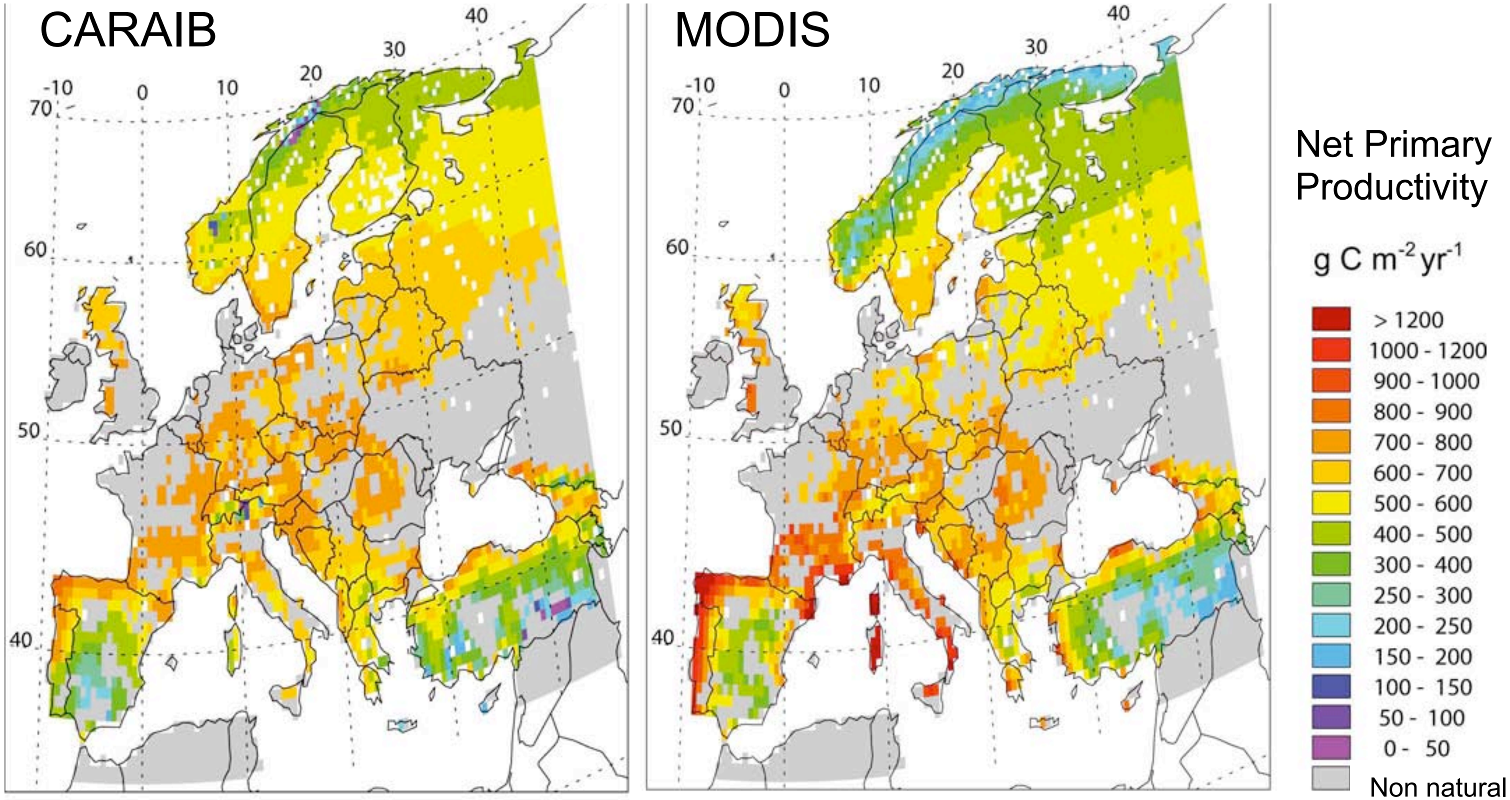
Evapotranspiration

Net Ecosystem Exchange



Minet et al., Biogeosciences, 2015.

Simulations at European Scale (NPP)



- simulations with CRU monthly climatic data at 0.5°x0.5° (2000-2006)
- grid cels with > 30 % (semi-)natural vegetation (mostly forests)
- comparison with MODIS NPP for the same period over

Dury et al. (2011)

Species-based simulations (Europe)

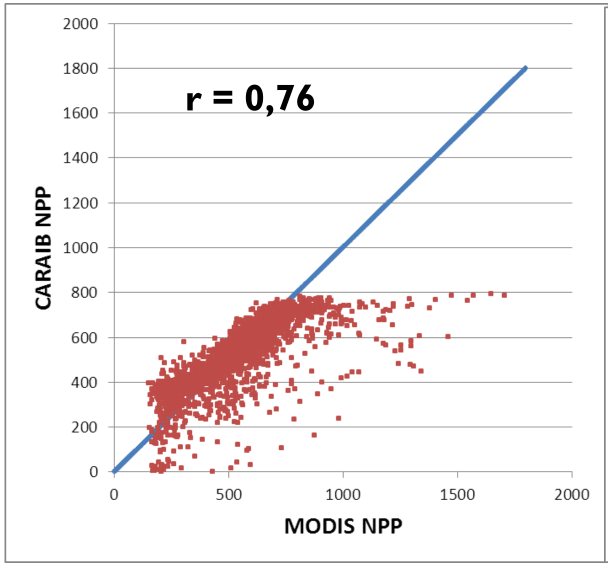
➔ simulations performed with species rather than BAGs or PFTs

➔ common European species representative of each BAG

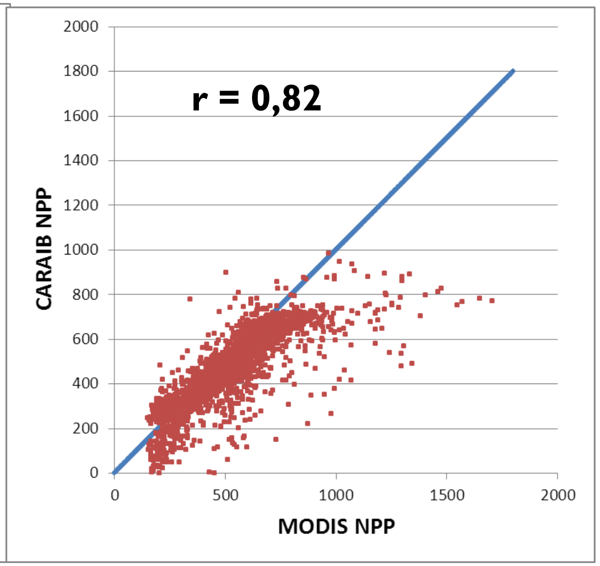
47 herbaceous species

12 shrub species

40 trees



Simulations with BAGs (shown before)



Simulations with species

Interannual Variability

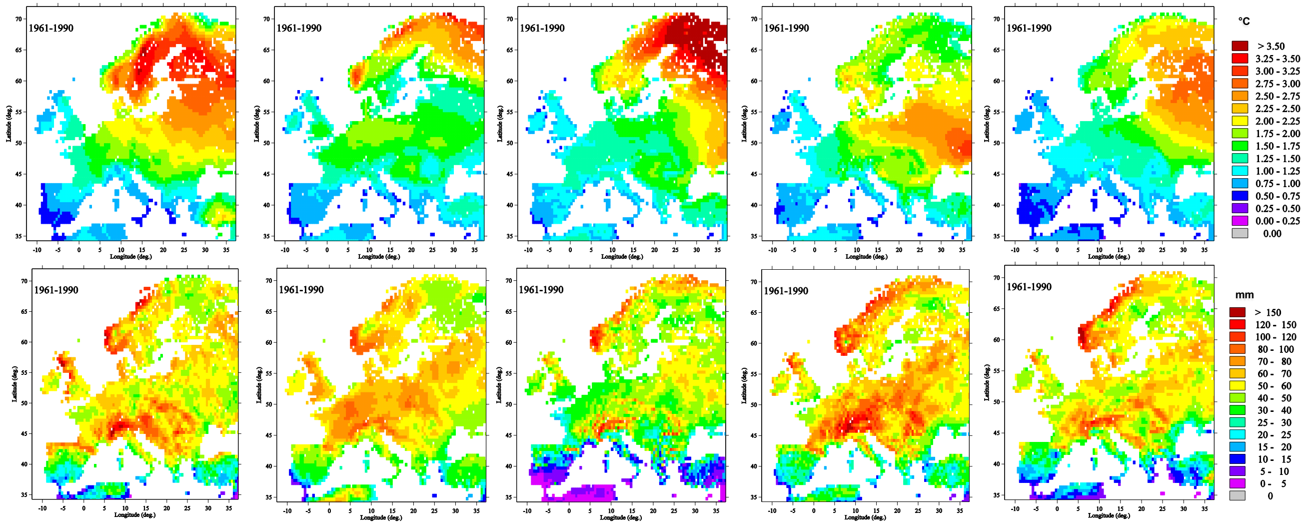
Interannual variability of climate and NPP (Models of ENSEMBLES project)

1961-1990

CRU | ARPEGE | DMI | HC | KNMI

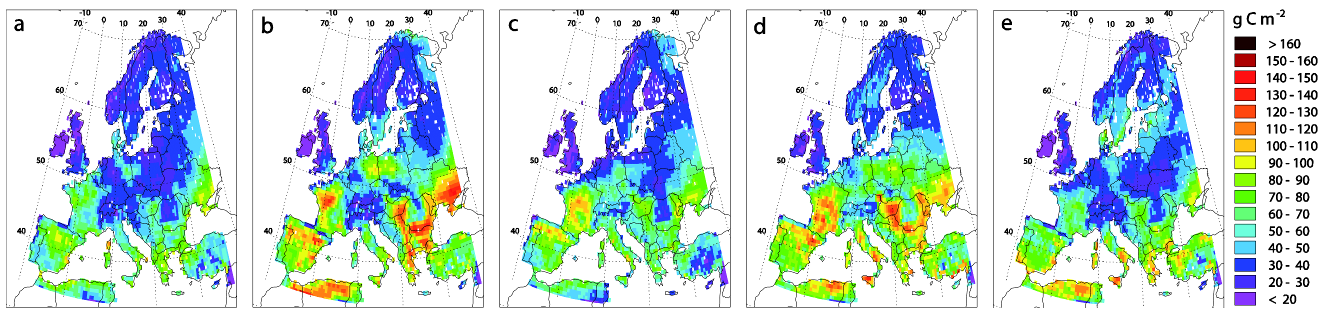
Winter temperature standard deviation

Summer precipitation standard deviation



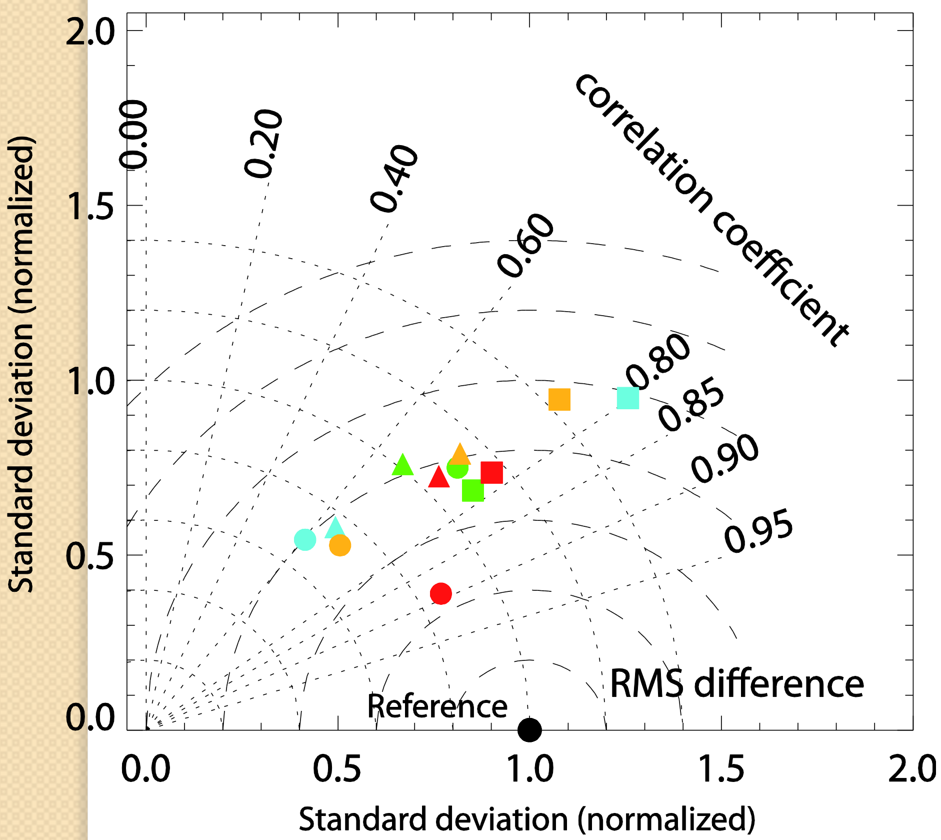
CARAIB

Annual NPP standard deviation



Dury et al., in prep.

Model performance to reproduce the 1961-1990 interannual variability (Taylor diagram / reference = CRU)



ARPEGE/Climate

DMI-HIRHAM5

HC-HadRM3Q0

KNMI-RACMO2

Reference CRU

- ● Winter temperature
- ▲ Summer precipitations
- ■ Net primary productivity

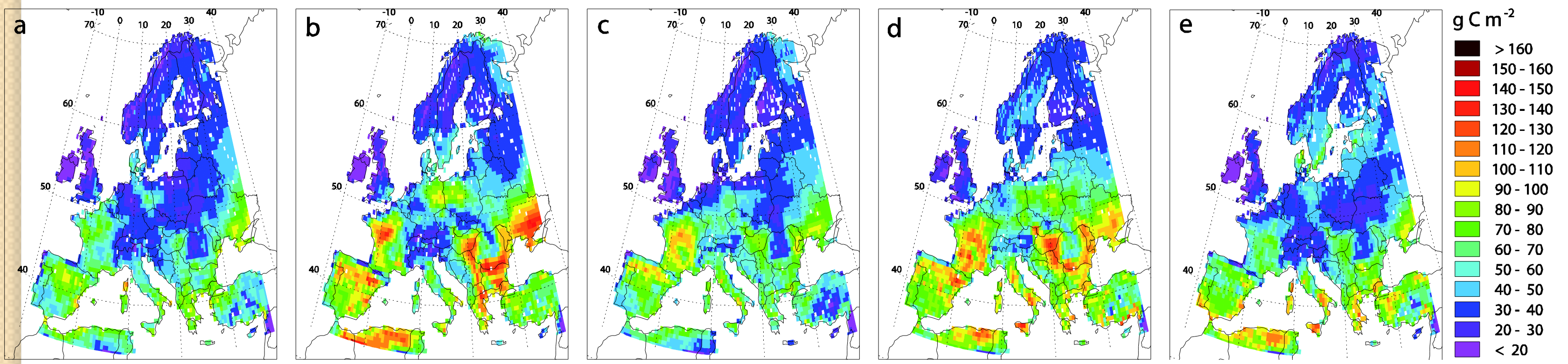
Future Impacts on Ecosystems

Future interannual variability of NPP

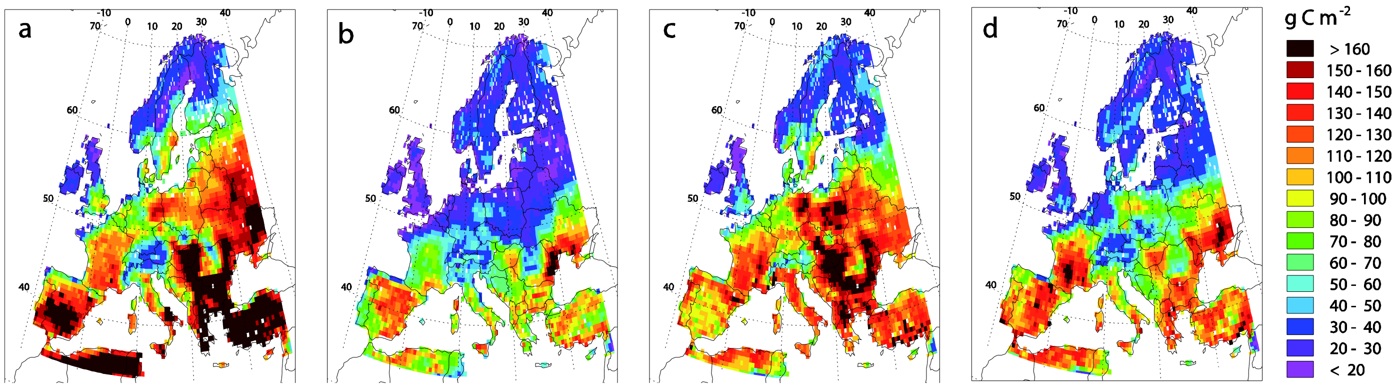
Annual NPP standard deviation

1961-1990

CRU **ARPEGE** **DMI** **HC** **KNMI**



2071-2100 (A1B)



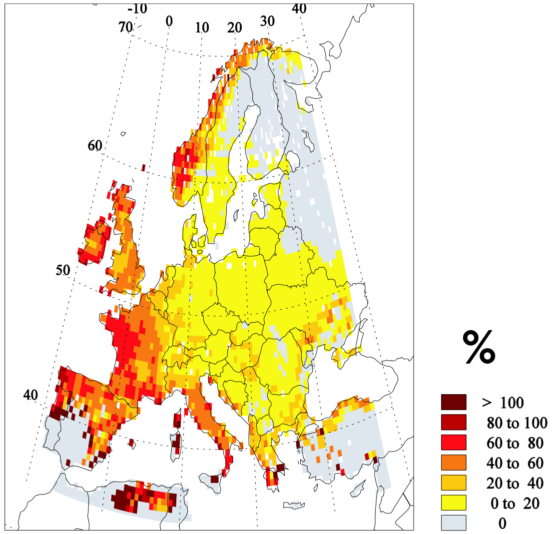
Dury et al., in prep.

Species distribution

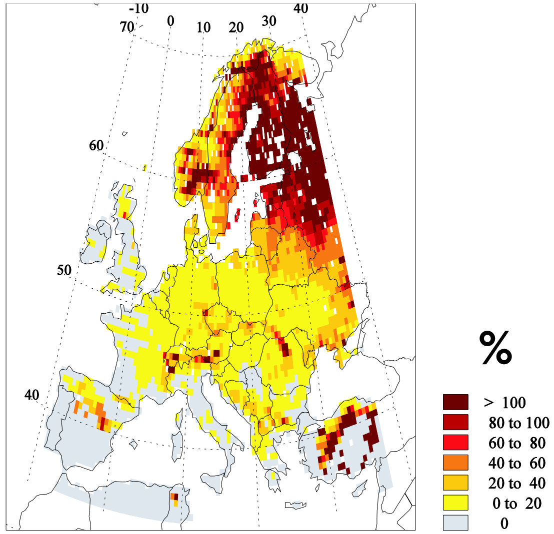
Percentages of species disappearance and potential appearance of new species between 1961-1990 and 2071-2100 **(KNMI-RACMO2 with *A1B SRES*)**

HERB and SHRUB SPECIES

DISAPPEARANCE

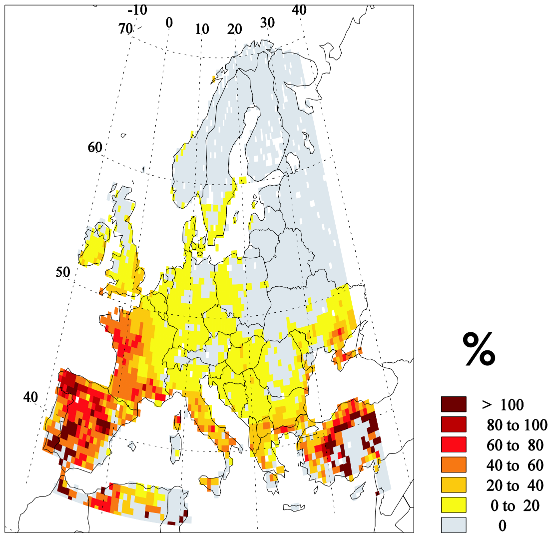


APPEARANCE

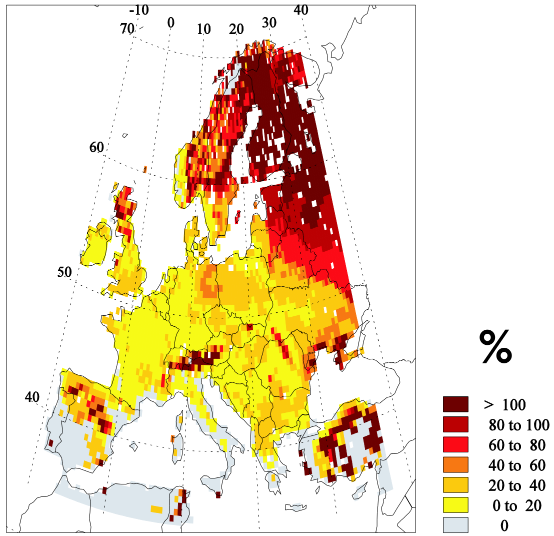


TREE SPECIES

DISAPPEARANCE



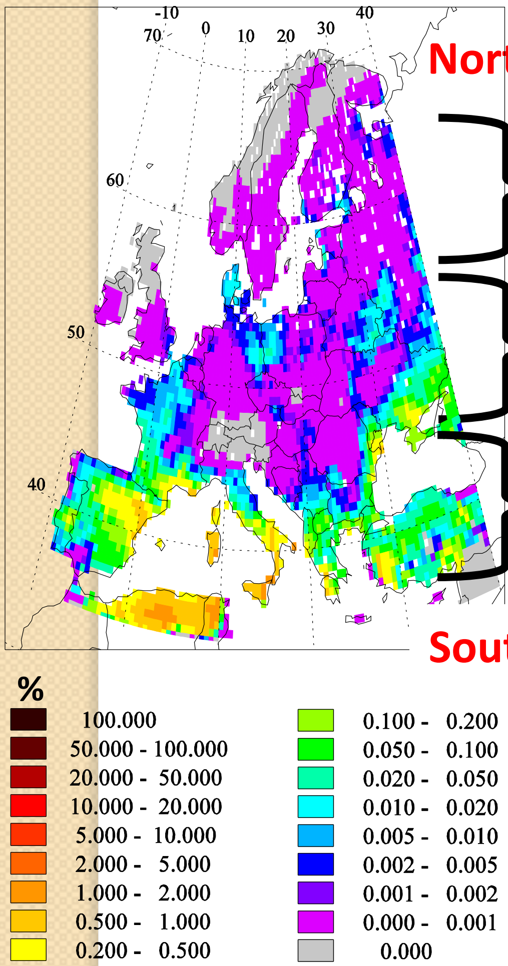
APPEARANCE



Natural fires

1961-1990

Percentage of pixel area burned per year



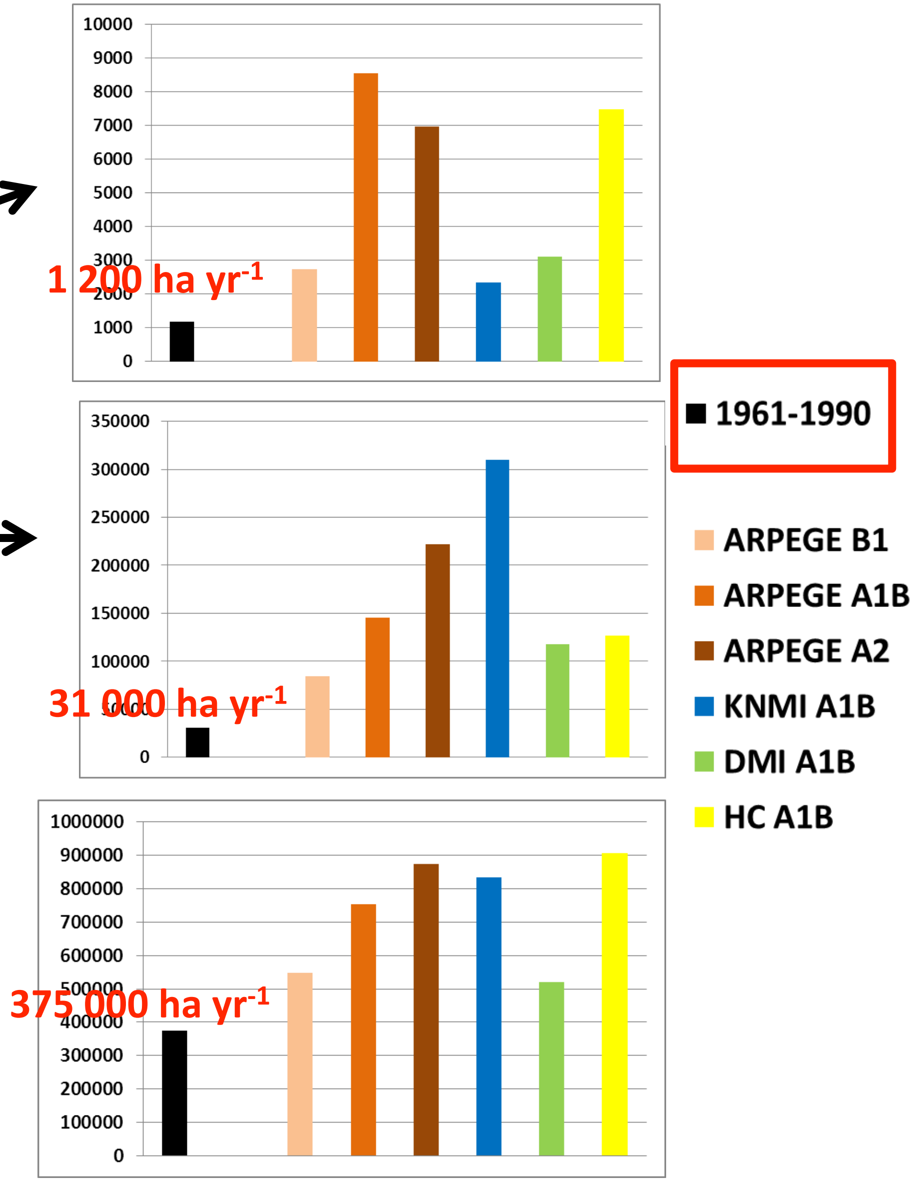
Northern Europe

Central Europe

Southern Europe

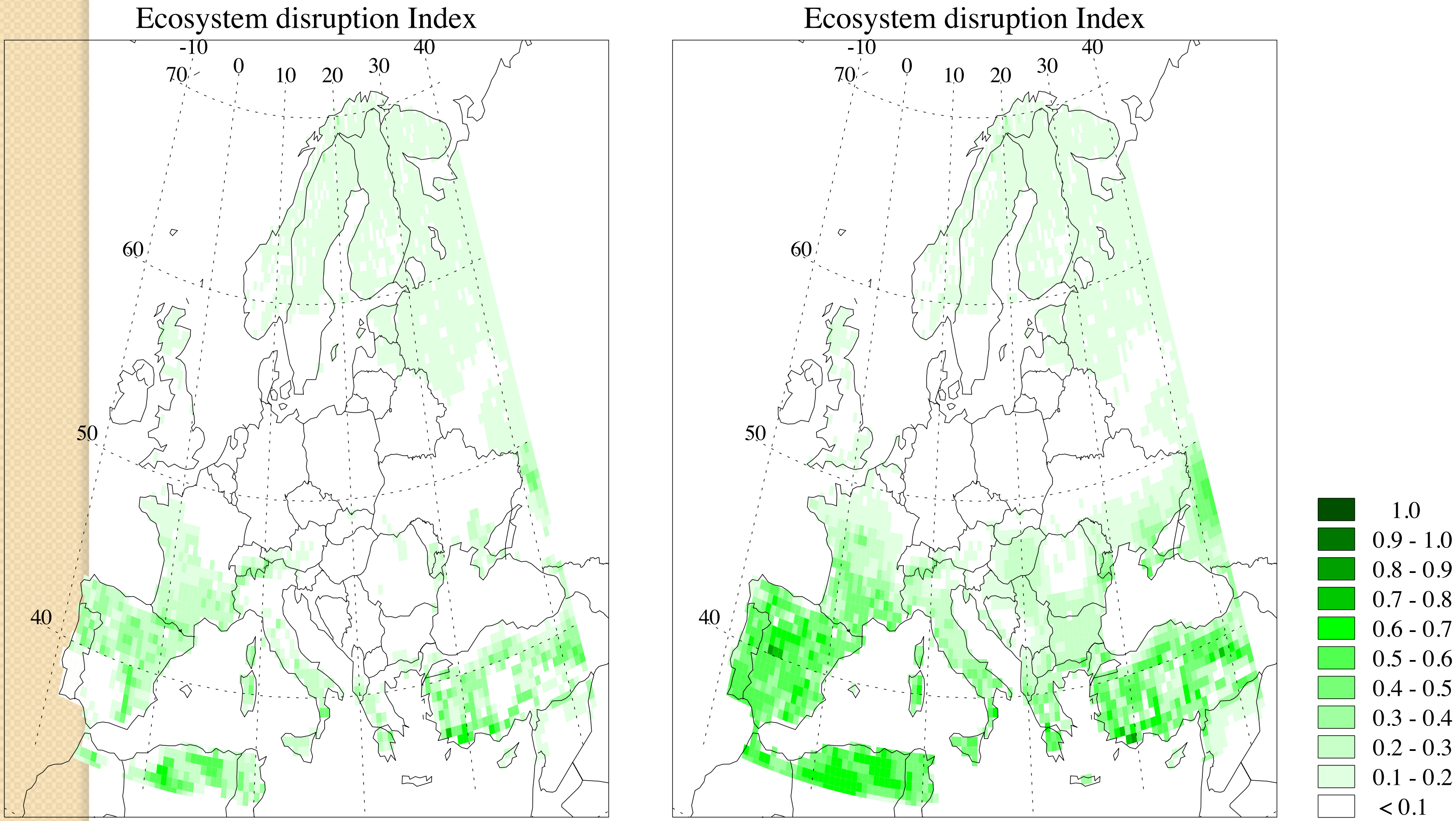
2071-2100

Area burned (ha) per year



Risk index for severe perturbation of ecosytems

-includes: runoff, NPP, fires, soil turnover, species disappearance, new species



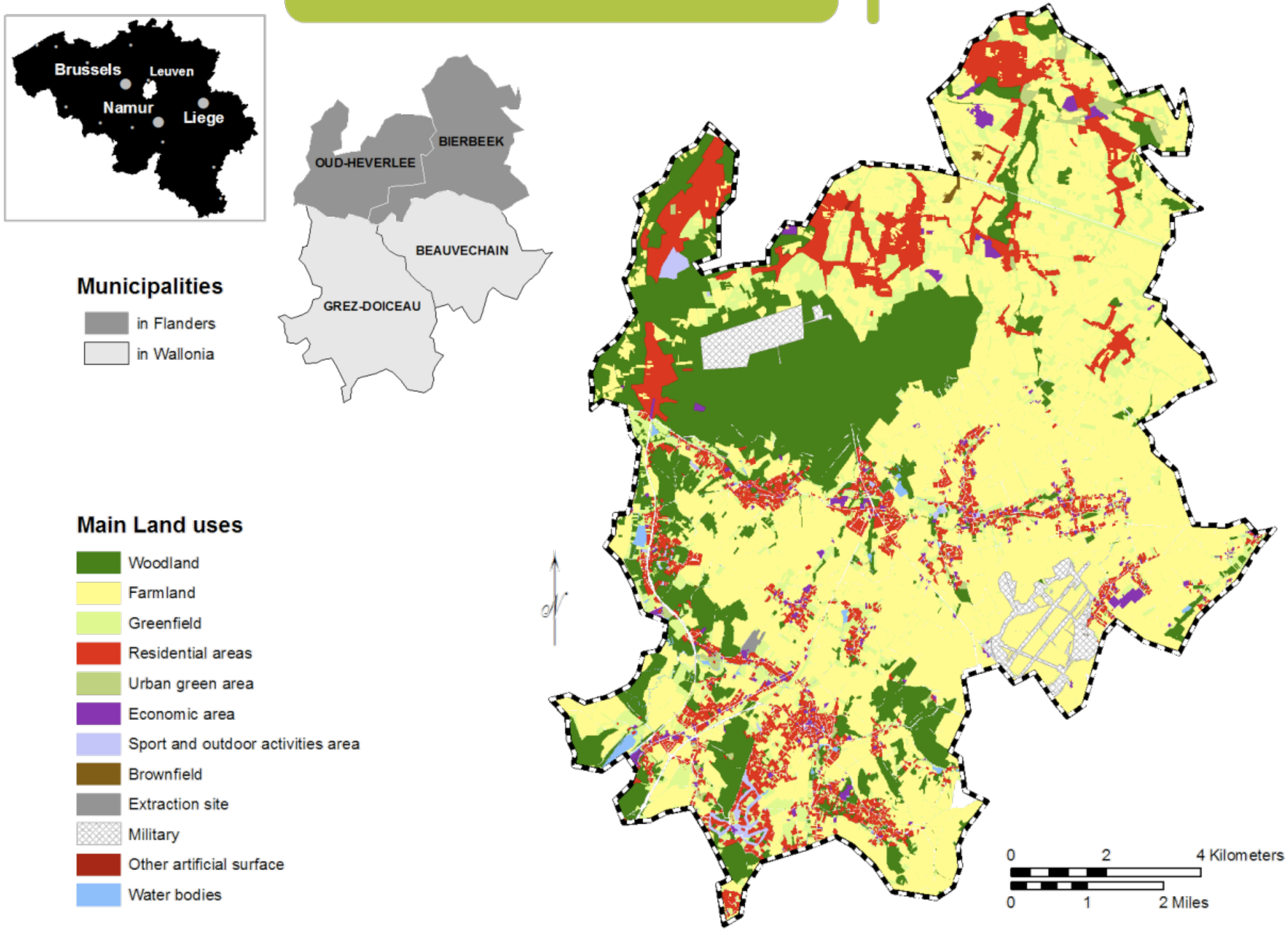
With CO_2 fertilization

Without CO_2 fertilization

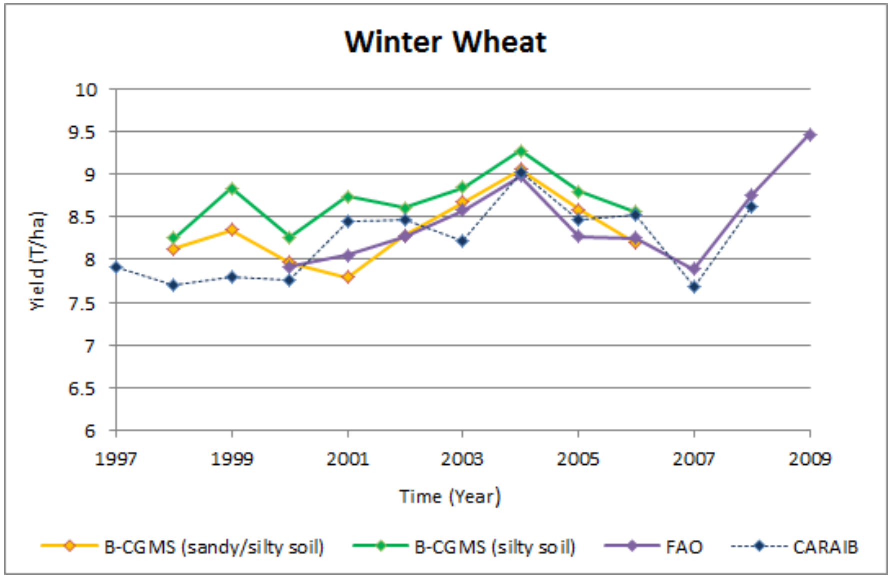
***(KNMI-RACMO2 with** A1B SRES)*

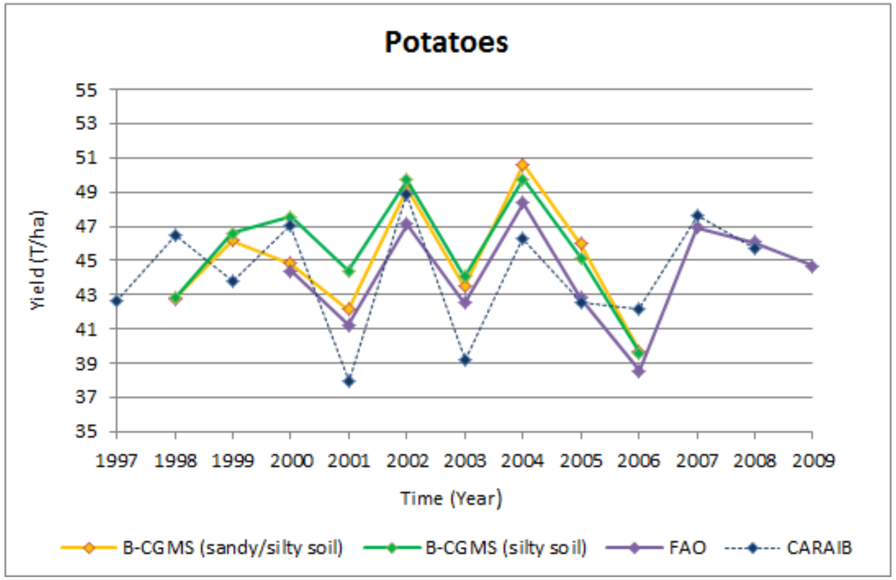
Integrating Crops and Ecosystem Services (VOTES)

VALUATION OF TERRESTRIAL ECOSYSTEM SERVICES



The main land uses in the four municipalities included in the Case Study Area for the VOTES project



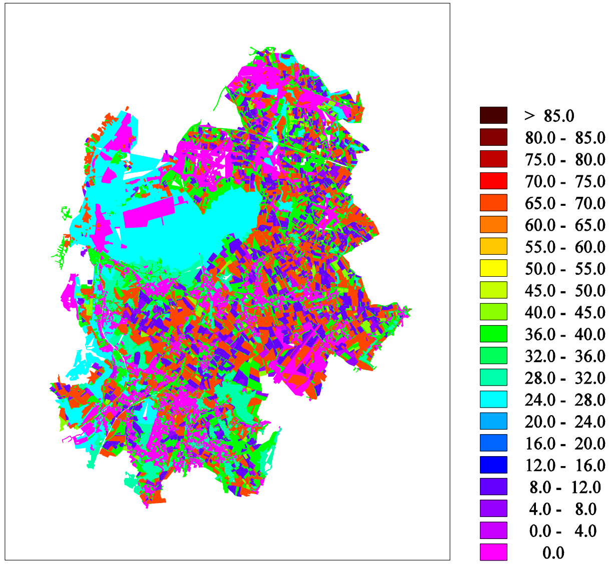


Development of a crop sub-model

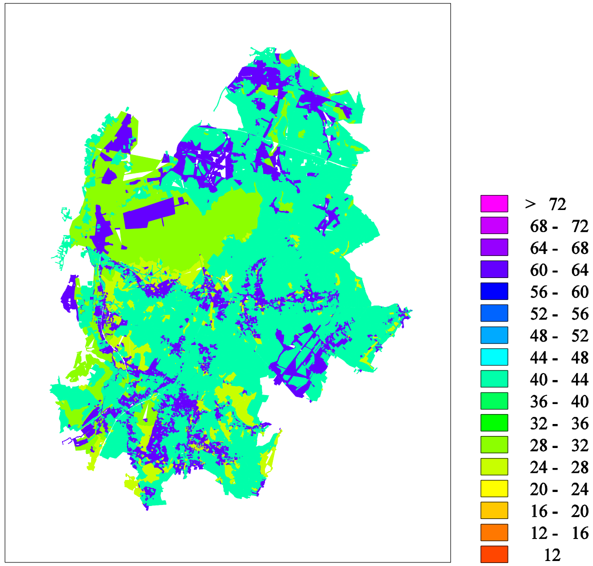
Variation of yields between 1997 and 2008 calculated by CARAIB for two crops (winter wheat and potatoes) growing in the VOTES case study area and compared to estimates from FAO and B-CGMS

Valuating Ecosystem Services

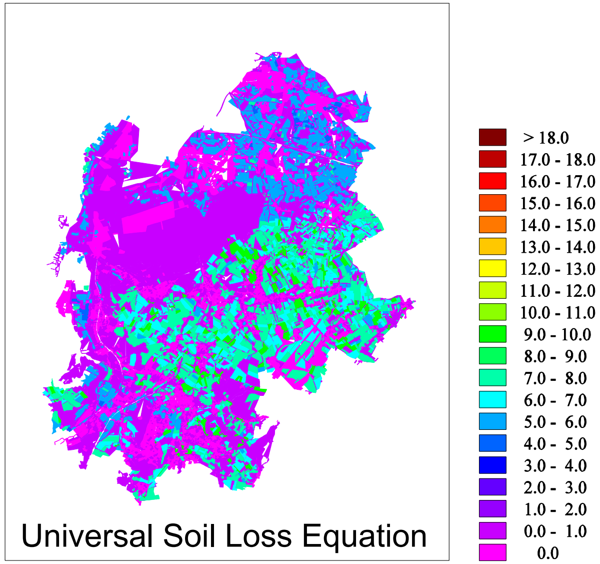
Yield (t ha^{-1} yr^{-1})



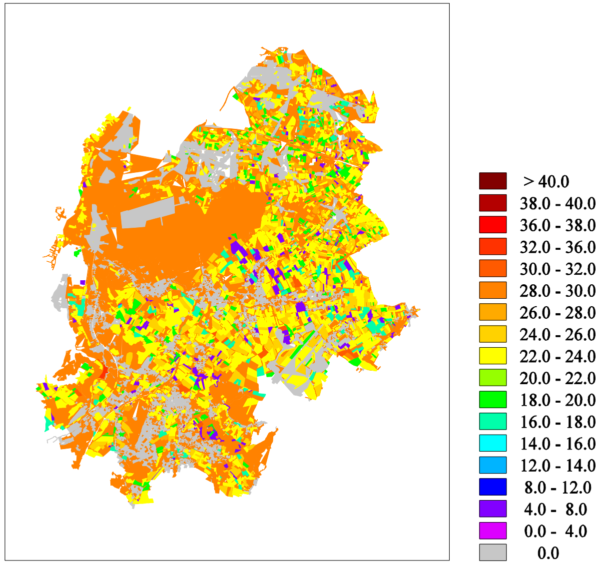
Runoff (mm/mo) [Maximum]



Soil loss (t ha^{-1} yr^{-1})



Soil Carbon (kg C m^{-2})

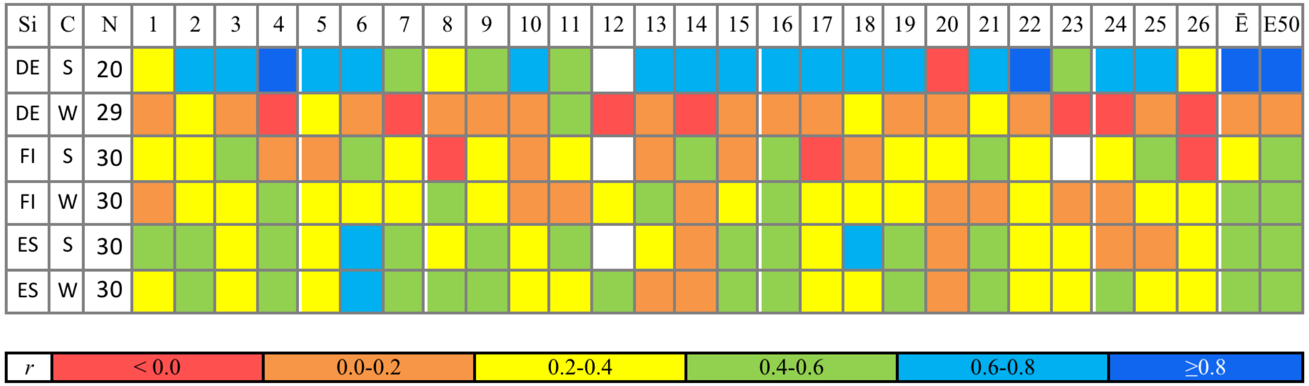


Simulation at plot scale

Modelling European Agriculture with Climate Change for Food Security
— a FACCE JPI knowledge hub —

FACCE-JPI – MACSUR intercomprison of crop yields

Pirttioja et al. (in prep.)



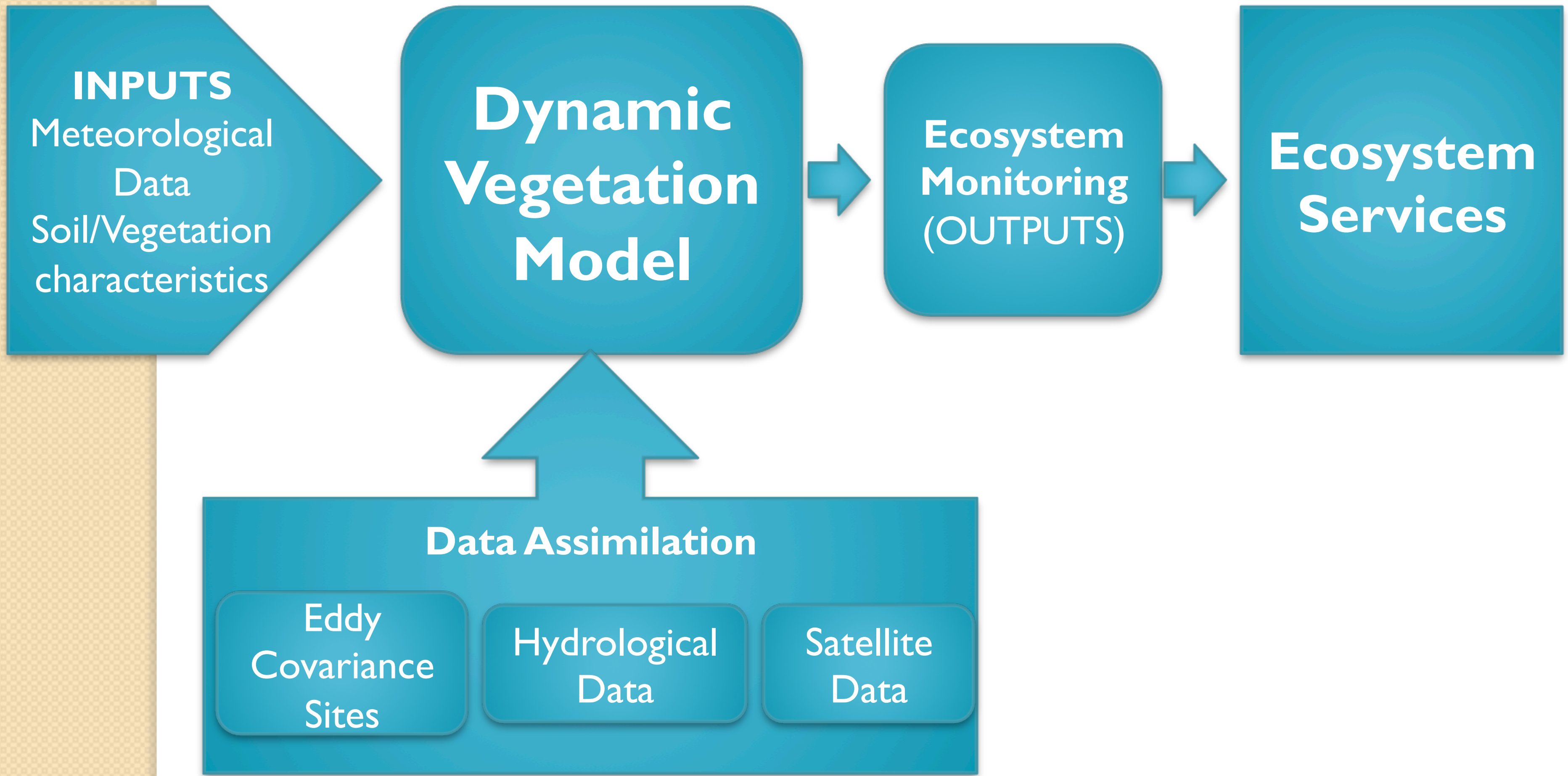
Correlation coefficients (r) for simulated versus observed yields over periods of N years during 1981-2010. Sites with spring (S) and winter (W) wheat are simulated in Germany (DE), Finland (FI) and Spain (ES) by 26 different models. Ē and E50 are the model ensemble mean and median, respectively. Colours in cells denote the magnitude of r.

ID	Model
1	AFRCWHEAT2
2	APSIM-Nwheat 1.55
3	APSIM-Wheat (modified) 7.5
4	AquaCrop 4.0
5	ARMOSA13.04
6	CARAIB Crop
7	CERES-wheat DSSAT v.4.5
8	CERES-wheat DSSAT v.4.5
9	CERES-wheat DSSAT v.4.6
10	CropSyst 3.02
11	DNDC 9.5
12	Fasset 2.5
13	HERMES V 4.26
14	LINTUL-4 v6
15	LPJ-GUESS
16	LPJml
17	MCWLA-Wheat 2.0
18	MONICA 1.2.5
19	SALUS
20	SIMPLACE<Lintul2, Slim>
21	Sirius 2010
22	SiriusQuality 2.0
23	SPACSYS 5.0
24	STICS V6.9
25	WOFOST 7.1
26	WOFOST 7.1

Conclusions and Perspectives

Towards an integrated tool for upscaling

CARAIB is a dynamic vegetation model able to represent ecosystem heterogeneity at **different scales**. It includes both **natural and crop ecosystems**. It could be used in data assimilation mode, as an **upscaling tool**, towards **monitoring of ecosystems and ecosystem services**.



Thank you