STIMUL Kick Off meeting

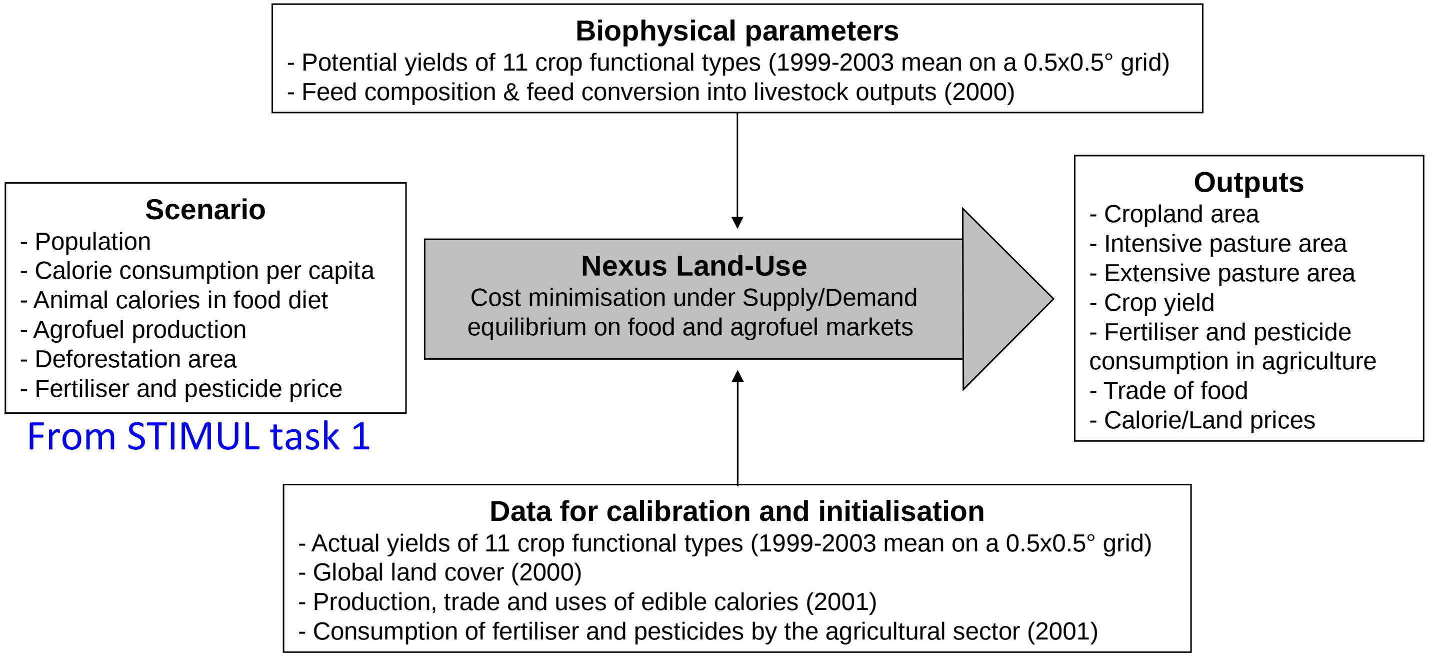
Discussion on the coupling between NLU and ORCHIDEE CROP

Philippe Ciais, Nathalie de Noblet, Xuhui Wang et al.

18/01/17

Nexus land use model - NLU

Potential yields presently calculated by LMPmL
=> can be calculated by ORCHIDEE CROP



From STIMUL task 1

From STIMUL partners (farm scale data / NUTS0 Eurostat ?)

All the presentation is based on NLU as in the Souty *et al.* publication GMD 2012

Potential yields

- Concept is a bit fuzzy, can be approximated by " maximum attainable yield under current climate and breeding technology"
- Conversion from mass to calorie is done by NEXUS averaged across all crop types (11) of LPJmL – Do we need an update to account for nutritional quality, i.e. preference for some crop types?
- Can "potential yield" be calculated from a fully irrigated run of ORCHIDEE crop ? – Answer is YES in principle
- Should it account for future climate and CO_2 ?

Potential yields : from LPJmL to ORCHIDEE-crop

Potential yields in LPJmL

LPJmL describes crop production with 11 CFTs on a $0.5° \times 0.5°$ grid representing most of the cereals (4 CFT), oil seed crops (4 CFT), pulses, sugar beet and cassava with irrigated and rainfed variants (Table 3). Crops not included in LPJmL CFTs (e.g. sugar cane, oil palm, fruits and vegetables, etc.) are referred to as other crops. Climatic potential yields $y^{\mathrm{max}}_{\mathrm{CFT},l}$ in tons of fresh matter per hectare and per year (tons FM $\mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$) are computed by LPJmL for each of the 11 CFTs with irrigated and rainfed variants, at each grid point of global land area (l subscript), by setting management intensity parameters in LPJmL such that crop yield is maximized locally. Climatic potential yields are taken as a mean of five LPJmL simulation years between 1999 and 2003 in order to minimise the climatic bias due to interannual variability.

Management intensity is approximated in LPJmL via 3 parameters: (i) LAImax, the maximum leaf area index potentially achievable by the crops, representing general plant performance (fertilisation, pest-control), (ii) αa, a scaling factor between leaf-level photosynthesis and stand-level photosynthesis, which accounts for planting density and homogeneity of crop fields, and (iii) the harvest index HI, which determines the partitioning of accumulated biomass to the storage organs. These three parameters are assumed to be interlinked, i.e. high-yielding varieties (large HI) are used in intensively managed crop stands (Gosme et al., 2010). For details see Fader et al. (2010).

Actual yields in LPJmL

3.1.2 Actual yields computation in LPJmL

CFT actual yields $y^{\mathrm{actual}}_{\mathrm{CFT},l}$ in tons FM $\mathrm{ha}^{-1}\,\mathrm{yr}^{-1}$ are computed by LPJmL in the following way. First, LPJmL yield is determined, with an arbitrary intensity level of 5 for each grid point and averaged over the 1999–2003 period (intensity level is represented by the parametrisation of LAImax, αa and HI and ranges from 1 (low) to 7 (high, depending on the CFT)). Then, for each CFT and each country, a scaling coefficient is computed, such that the mean country yield matches the FAO yield over the same period. This mean country yield is calculated using annual fractional coverage of each CFT in

Geosci. Model Dev., 5, 1297–1322, 2012

In the NLU original paper, in some grid cells, the actual yields were higher than potential ones, in that case, actual yields were selected

In ORCHIDEE-CROP

yes we can offer …

- **GGCMI Phase 1 / ISIMIP Fast Track**

  runs available 0.5° - global

  5 crop types:

  wheat, maize, 3 rice, soy

  fully irrigated and rainfed

  planting density = actual

- **IMPACT2C and HELIX projects**

  runs available 0.5° - Europe

  Different climate and CO2 levels

- **GGCMI Phase 2 CTWN**

  0.5° - Globe

  Different treatments (cube) in each grid

  - 9 ΔT

  - 9 ΔP (up to fully irrigated)

  - 4 ΔCO2

  - 4 ΔN (simple function in ORC)

All runs performed by Xuhui Wang

Intensification response

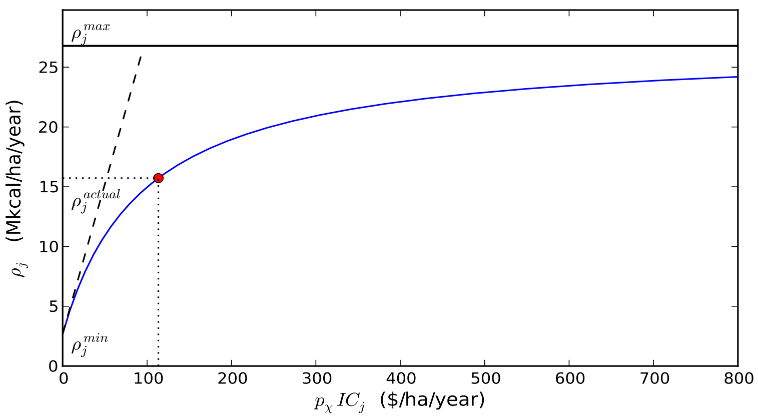


Fig. 8. Yield in a land class as a function of chemical input consumption IC_j. ρ_j^{max}, ρ_j^{actual} and ρ_j^{min} are the potential, actual and minimum yields of the land class j. p_χ is the price index of chemical inputs.

A central piece of NLU

Accounts for multiple input types (irrigation, fertilizers, pesticides, practice)

Needs a price for each input

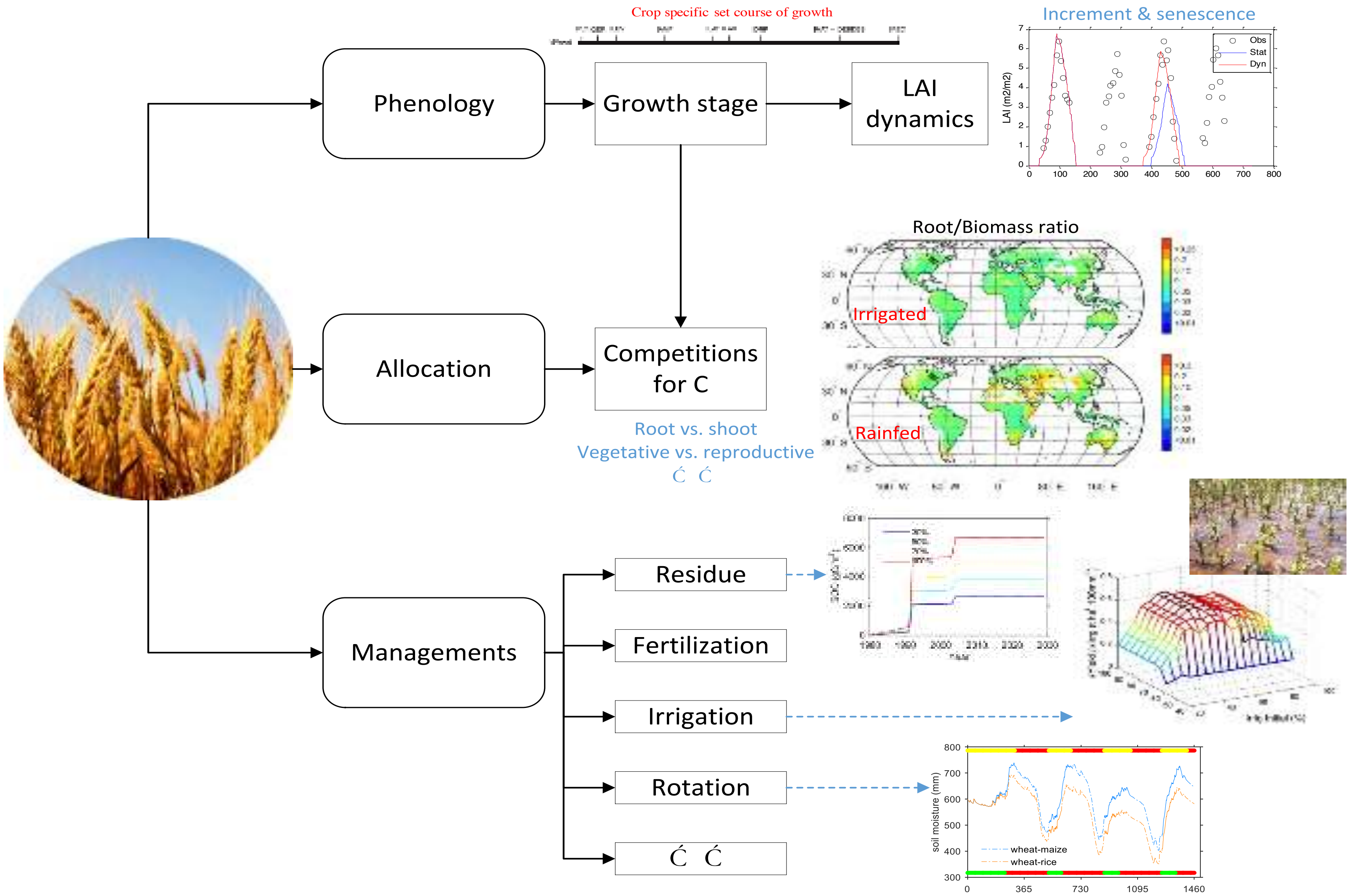
In ORCHIDEE crop, the explicit shape of this function can be simulated from GGCMI runs

- For different amounts of N (in a simplified way)
- For different amounts of water (in a detailed way)
- No pesticides
- No costs of N, water amounts

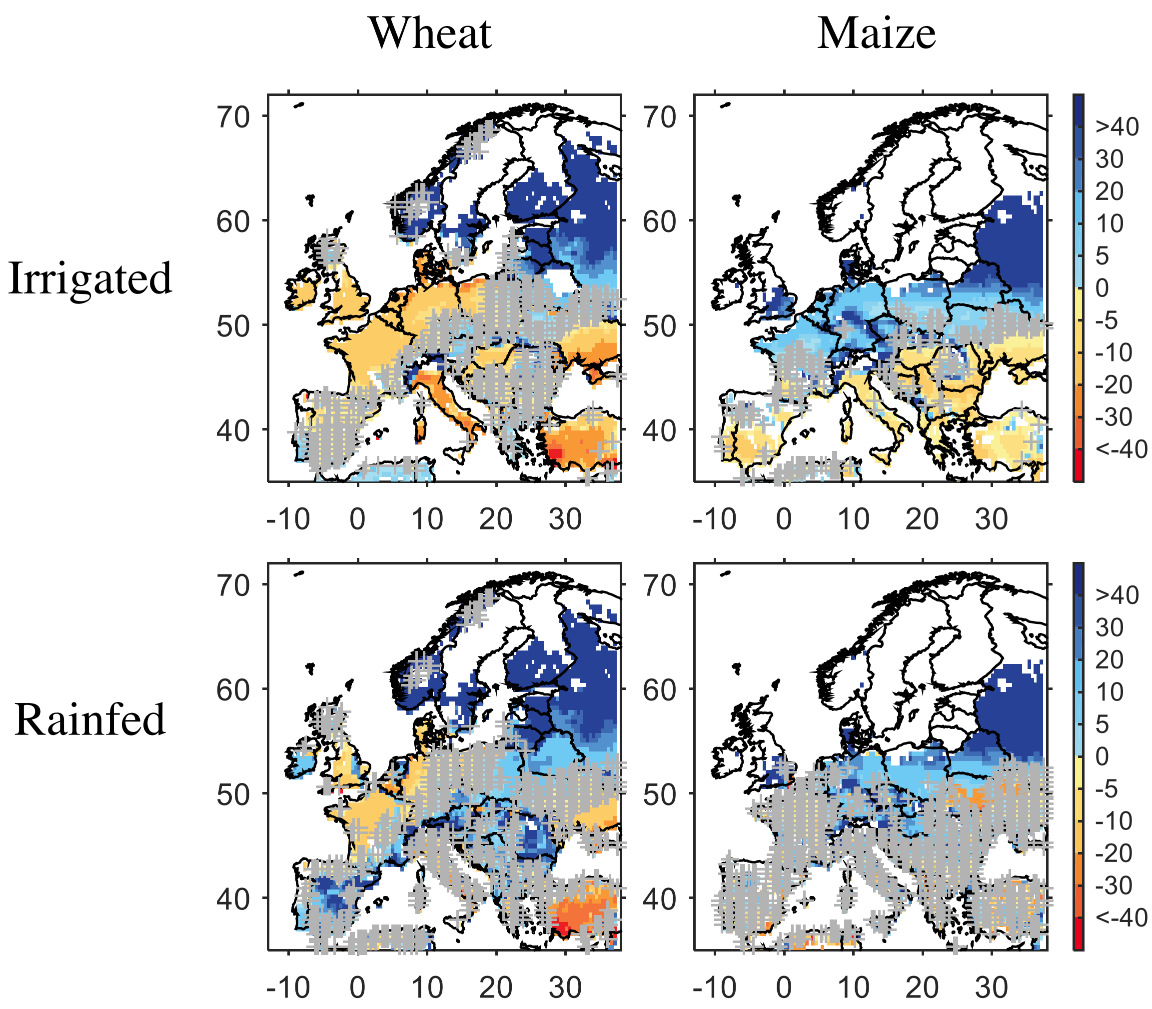
Pro and cons

- Smaller set of crop types in ORCHIDEE, may need to complete by LPJmL for non modeled types important in Europe
- ORCHIDEE uses a more mechanistic approach to calculate potential yields
- Future effects of climate (>0 or <0) and CO_2 (>0) on potential yields can be taken into account
- Response functions to N and water is likely more realistic than the aggregated response used in NLU at the moment

1. Simulations we can offer : GGCMI ISIMIP Fast track

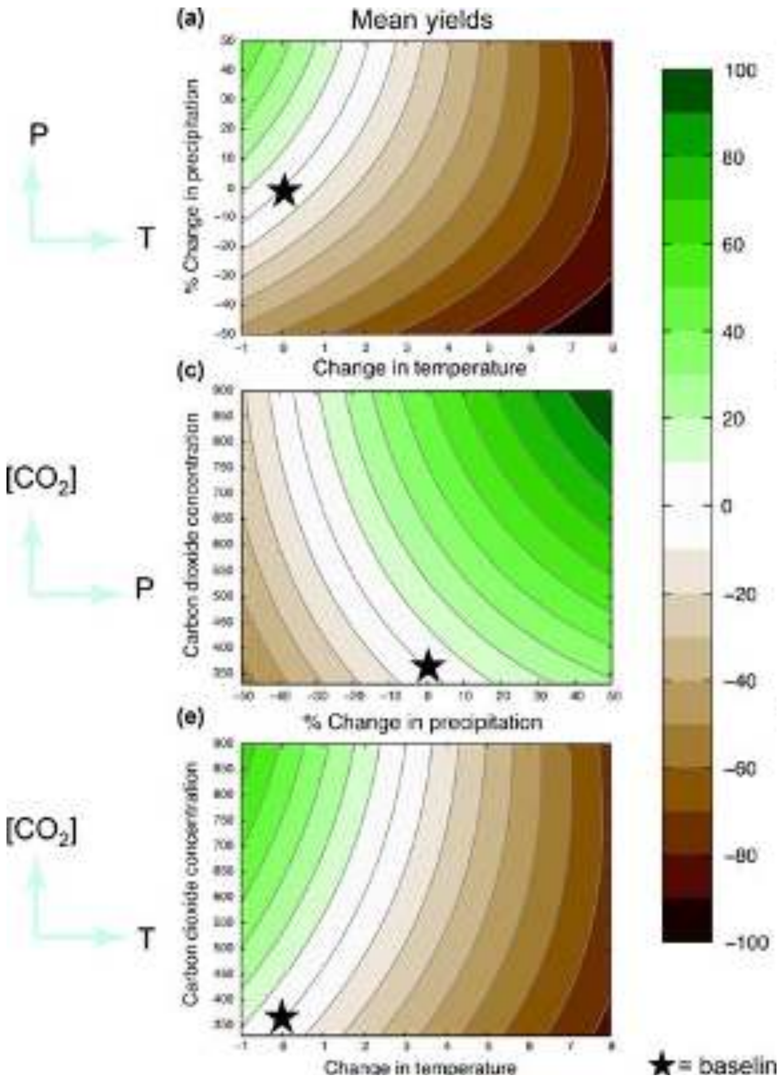


2. Simulations we can offer – IMPACT2C and HELIX European climate and CO_2



- The impact of 4K warmer climate on European croplands (HELIX)
- The impact of 2K warmer climate on European croplands (IMPACT2C)

3. Simulations we can offer : GGCMI Phase 2 CTWN analyses for global croplands



- 0.5 degree global simulations for model sensitivity to change in $[CO_2]$, T, P & Nitrogen
- 0.5^o global × 30 years ×4 CN settings × 9 TP settings

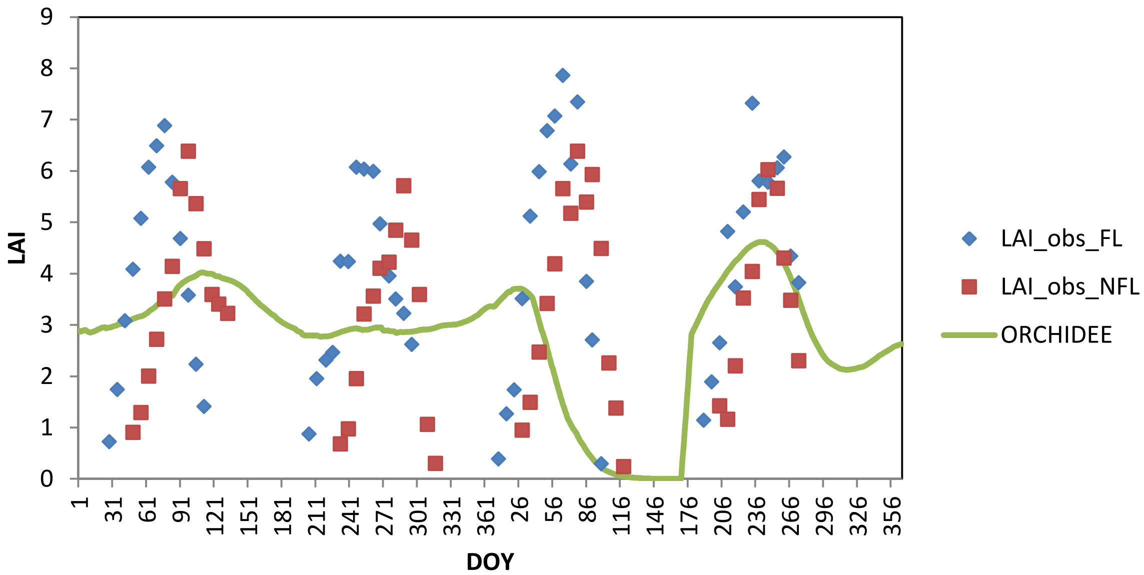
A short introduction to ORCHIDEE-crop 40 pages ☺

Slides from Xuhui Wang

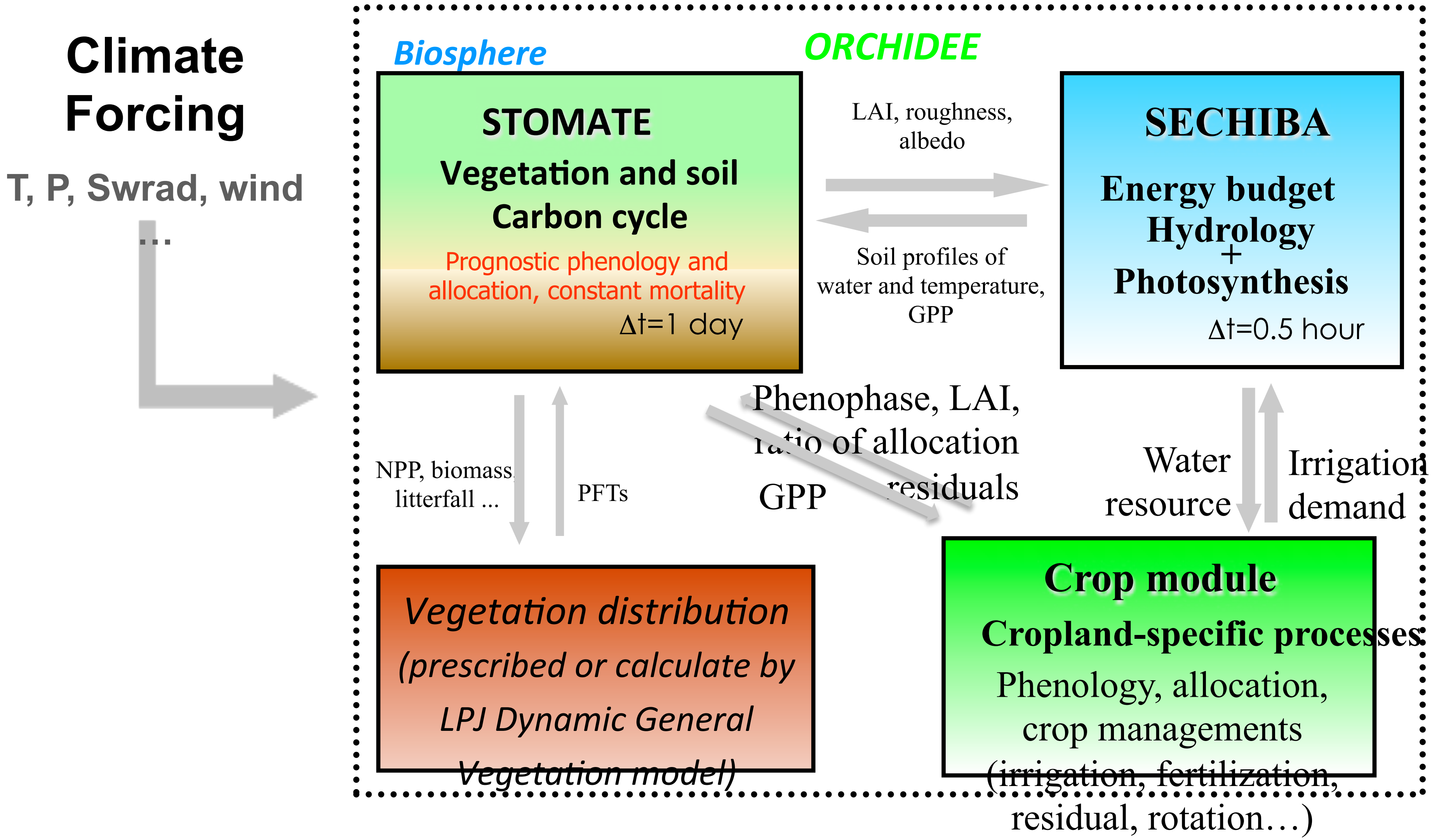
2017.01

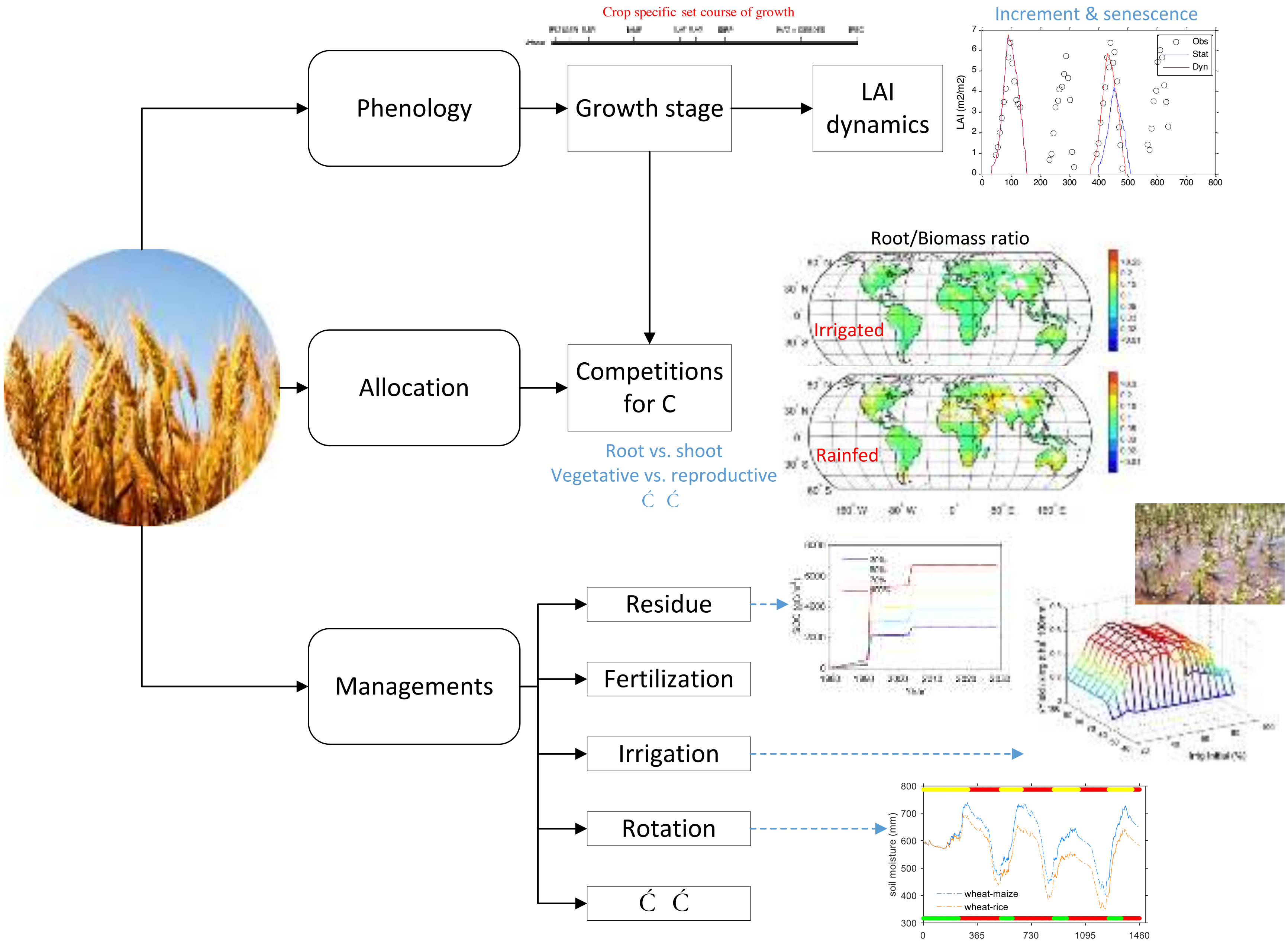
Limitations in simulating croplands by ORCHIDEE

IRRI site (14.2°N, 121.3°E)



ORCHIDEE-crop





Crop specific set course of growth
Increment & senescence
Phenology
Growth stage
LAI dynamics
LAI (m2/m2)
Obs
Stat
Dyn
Root/Biomass ratio
Irrigated
Rainfed
Allocation
Competitions for C
Root vs. shoot
Vegetative vs. reproductive
Managements
Residue
Fertilization
Irrigation
Rotation
soil moisture (mm)
wheat-maize
wheat-rice

Lists of sub-modules

- Growth dynamics
  - Phenology
  - Allocation

- Managements
  - Irrigation
  - Fertilization
  - Rotation
  - Residue management

Lists of sub-modules

- **Growth dynamics**
  - **Phenology**
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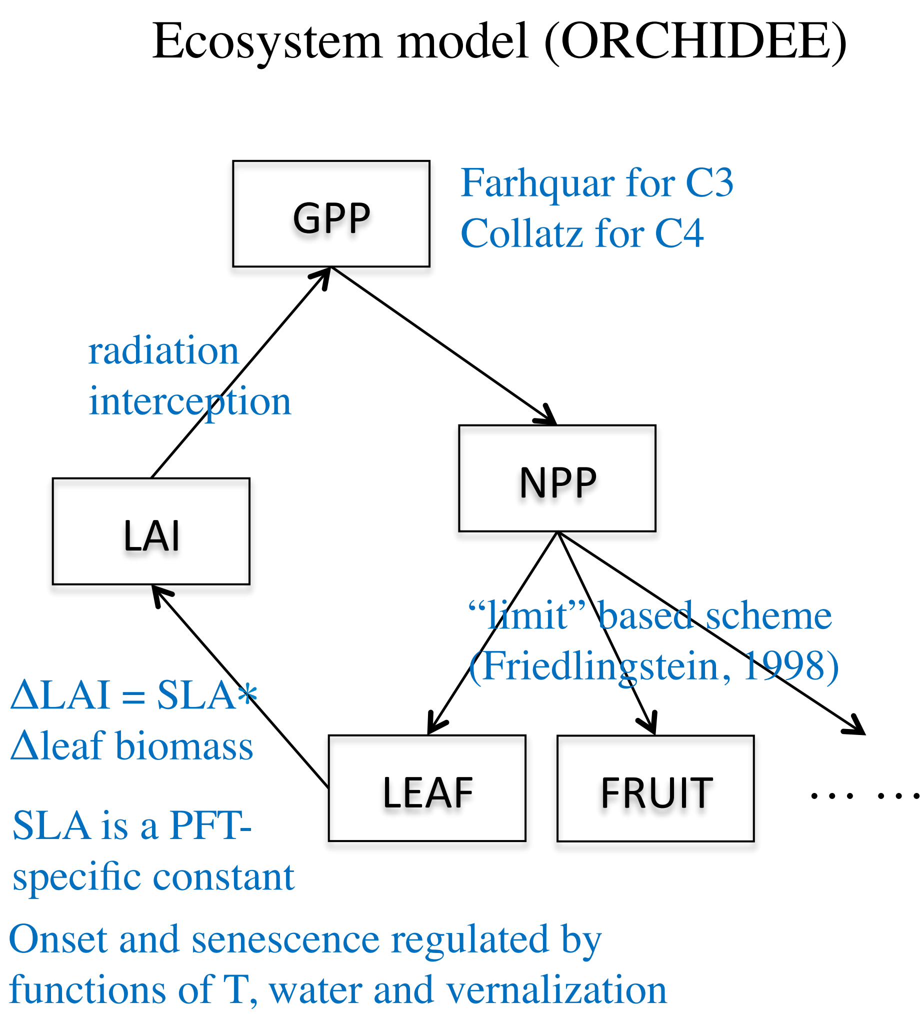
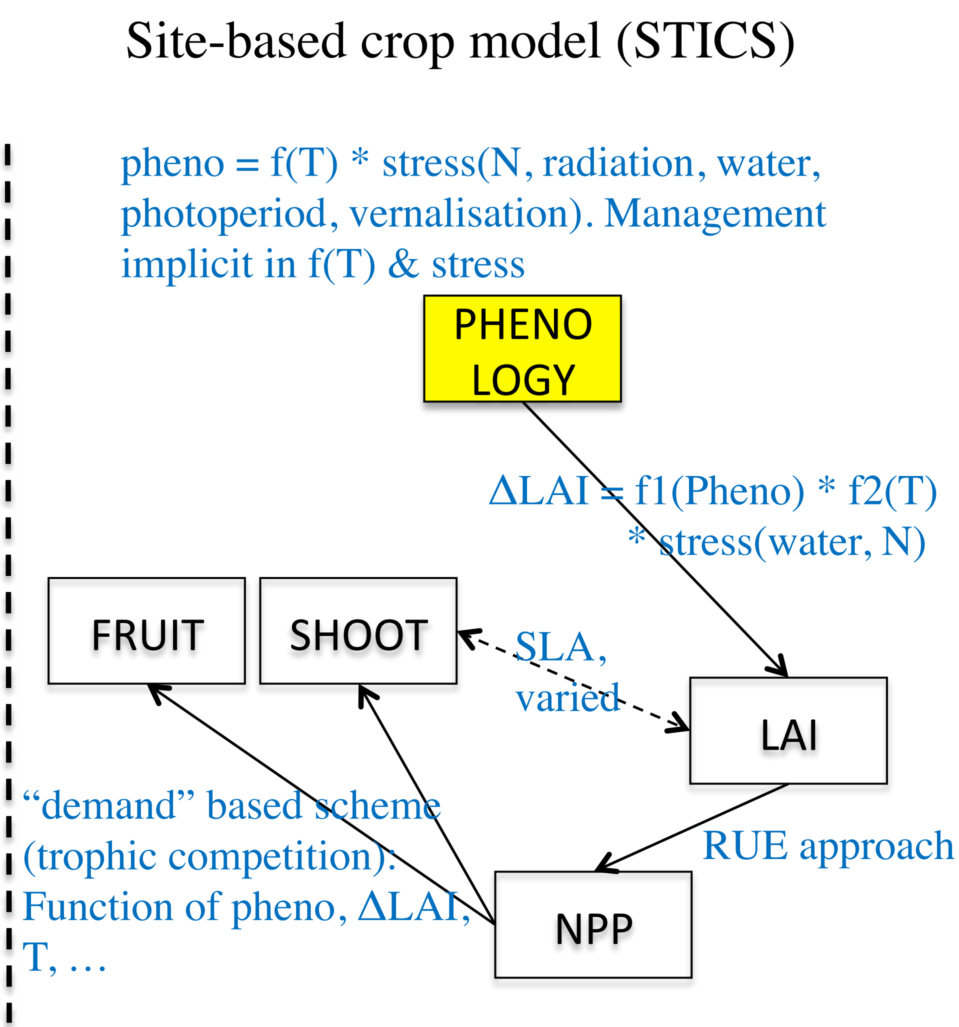
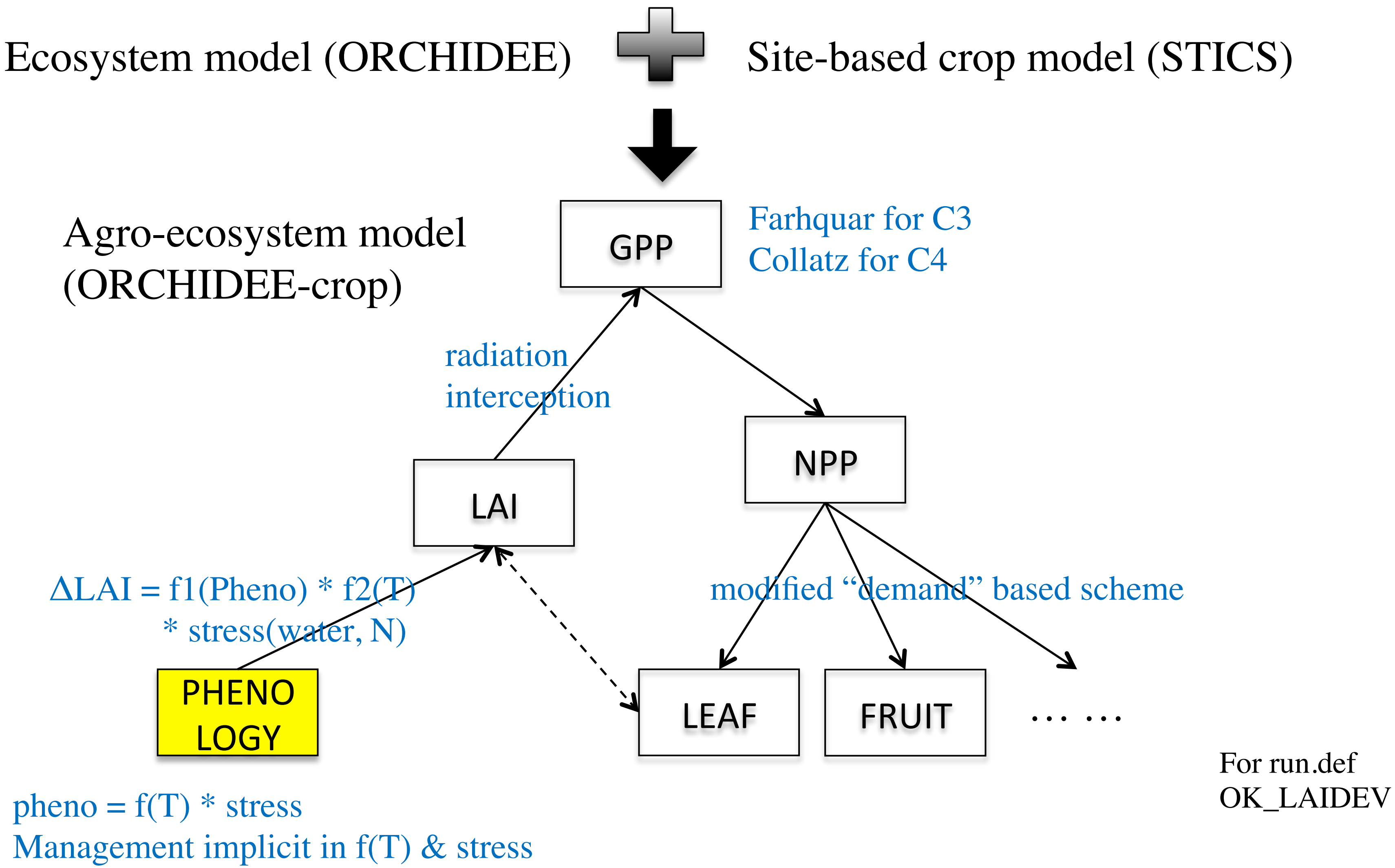
growth cycle simulation





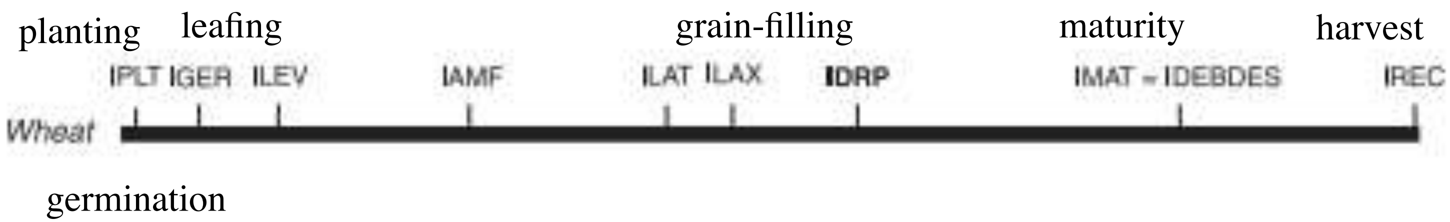
growth cycle simulation



Phenology progressing

$$\text{Growth } Unit = f(T) \times \delta_p \times \delta_v \times (\varepsilon \times \min(\delta_n, \delta_w) + 1 - \varepsilon) \quad (Eq. 1)$$

The phase of the growth is a joint function of temperature, precipitation, vernalization demand, nitrogen & water stress

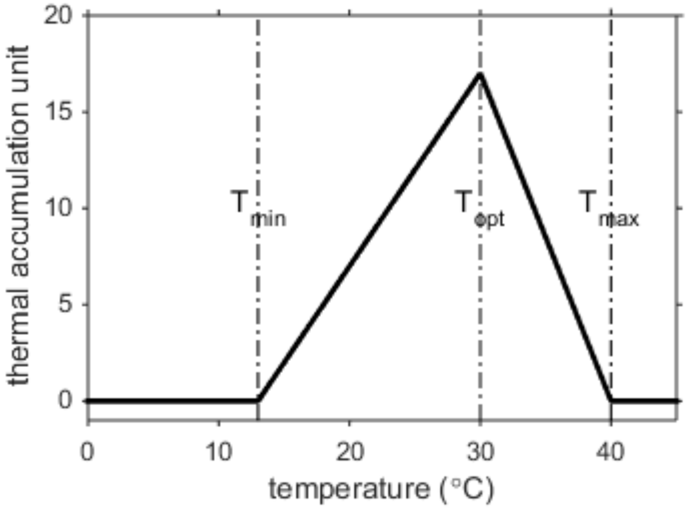


LAI as a function of phenology

For ORCHIDEE-crop, LAI is no longer diagnostic of leaf biomass increment * SLA, but a prognostic variable

$$\Delta LAI_{inc} = f(dev) \times f(T) \times f(stress)$$

$$\Delta LAI_{sen} = f(GDD) \times f(stress)$$



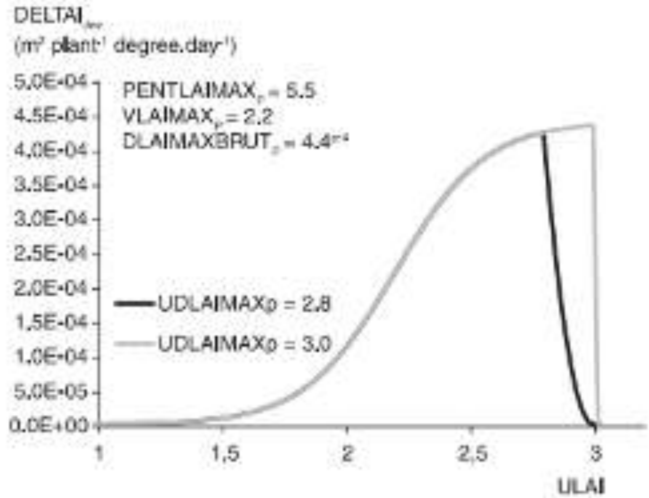
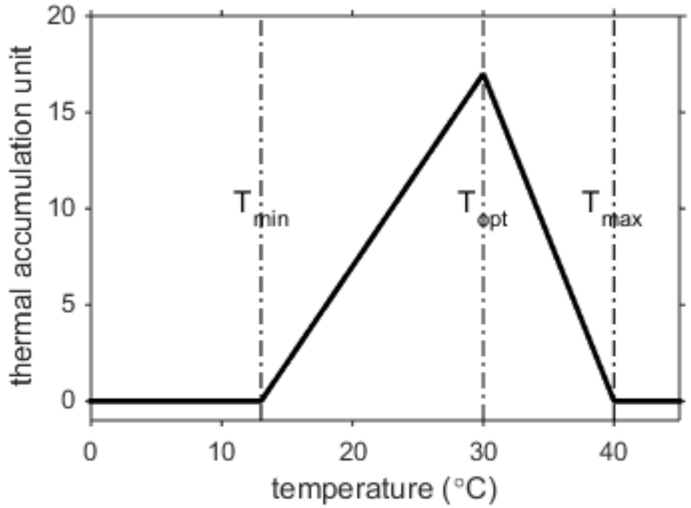


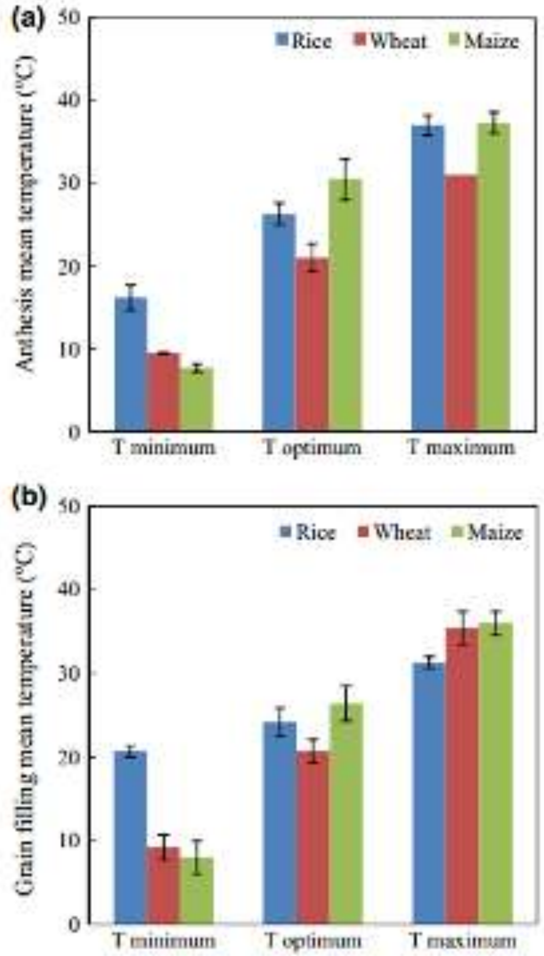
Figure 3.2. Leaf growth rate as a function of phasic development with the parameterization corresponding to wheat crop as given in Singels and Jagger (1991) with two hypotheses for leaf growth slowing at ILAX through the parameter $UDLAIMAX_p$ and consequences for the LAI curve shape.

The temperature thresholds

Crude but useful



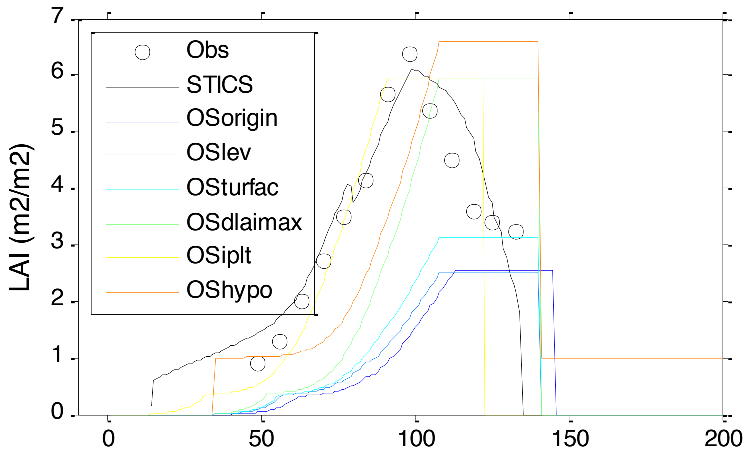
Wang et al., in review

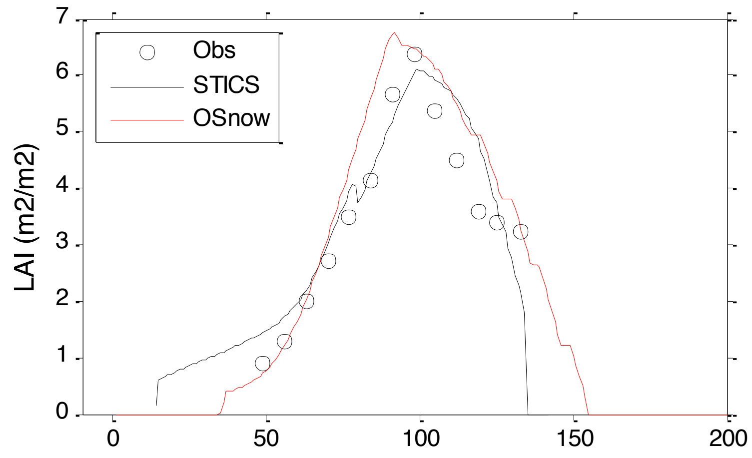


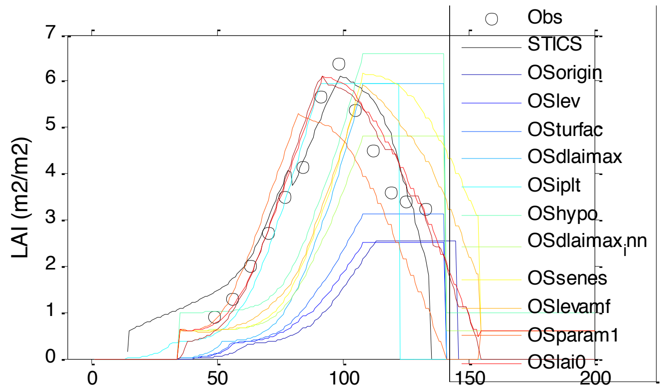
Sanchez et al., 2015

Fig. 2 Rice, wheat and maize (in separate columns with SE). (a) Mean minimum, optimum and maximum temperatures for anthesis, (b) Mean minimum, optimum and maximum temperatures for grain filling.

The importance of senescence

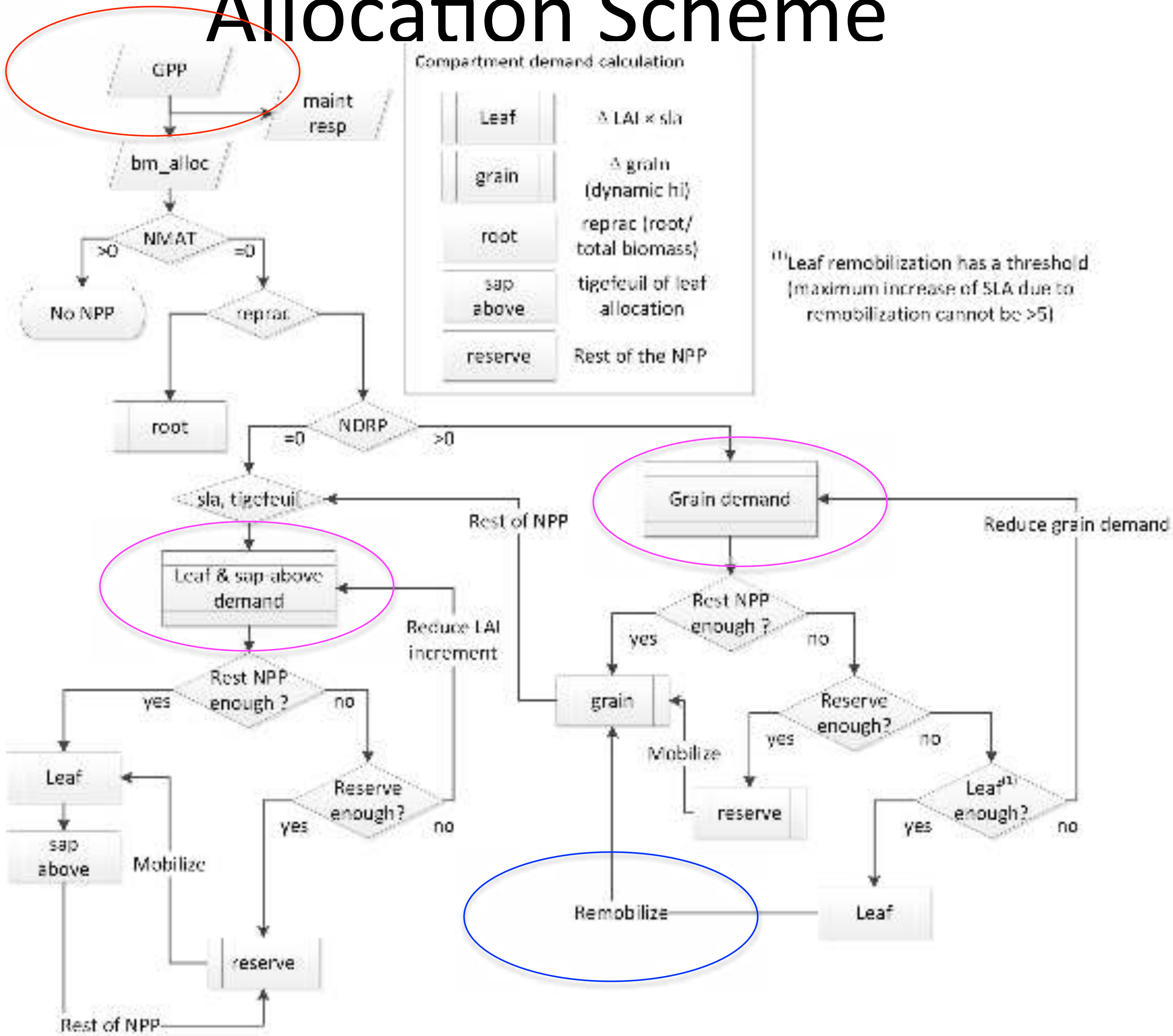






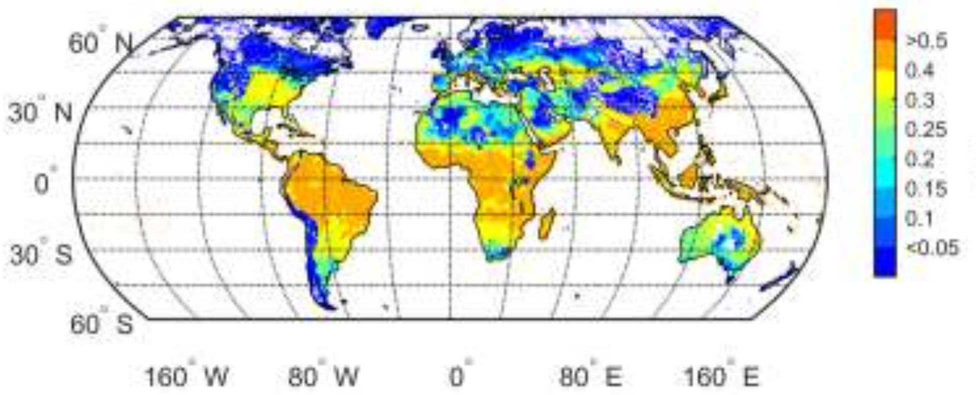
For run.def
DURVIEF

Allocation Scheme

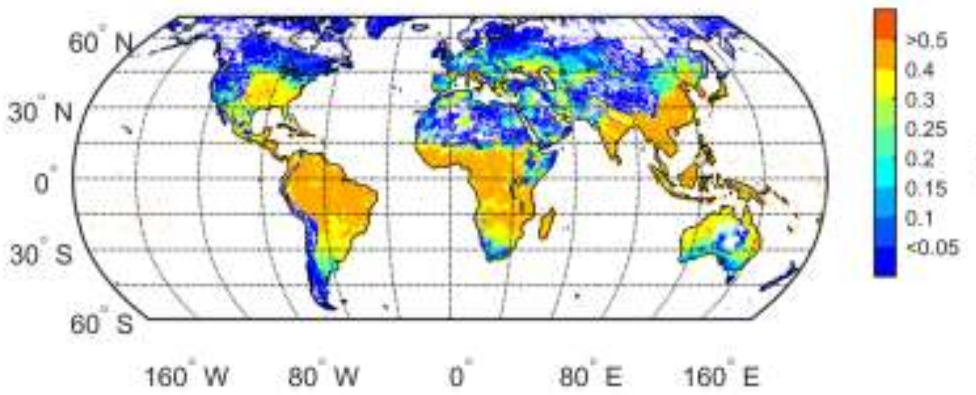


Harvest Index

Irrigated

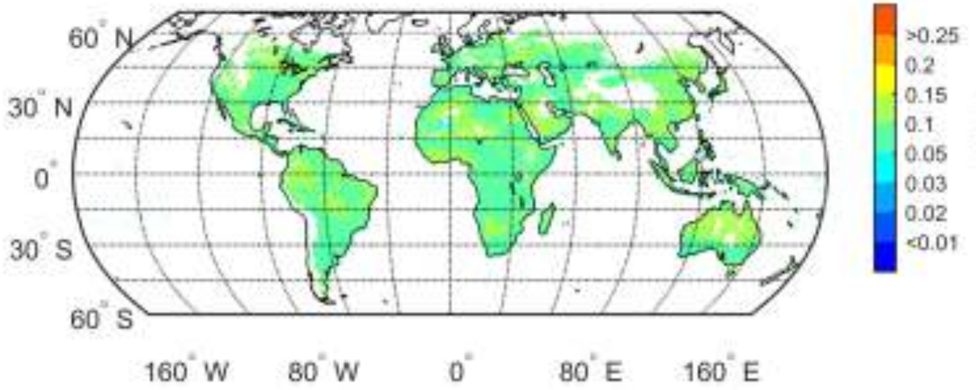


Rainfed

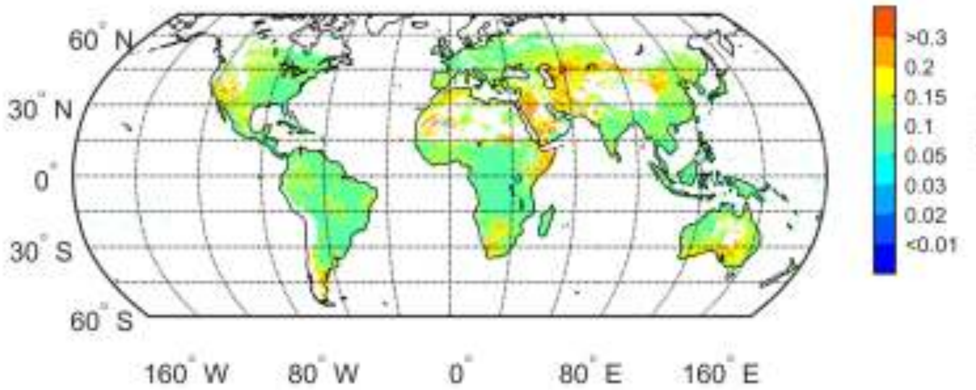


Root/shoot ratio

Irrigated

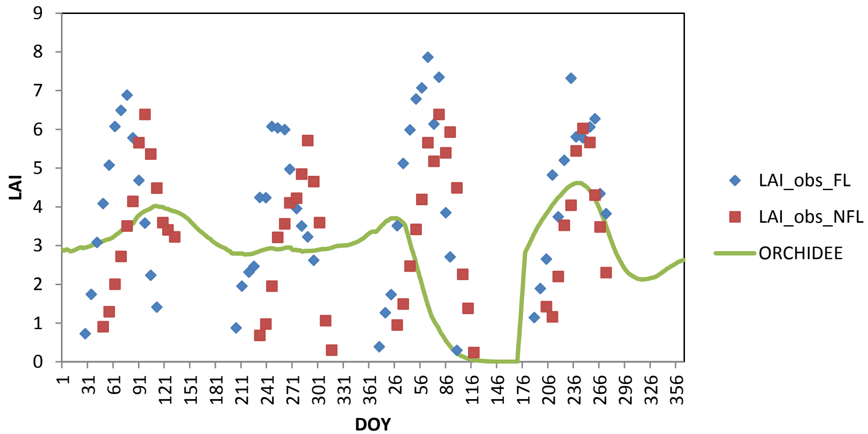


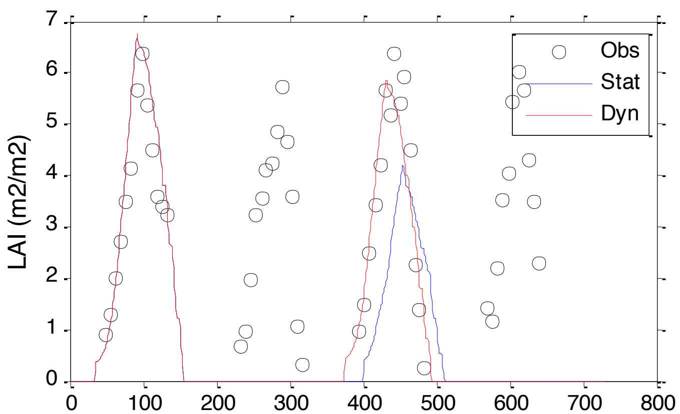
Rainfed



One step ahead

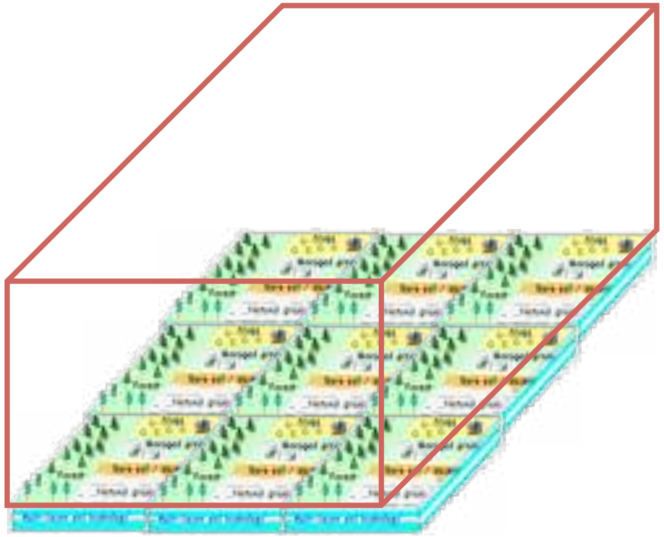
IRRI site (14.2°N, 121.3°E)



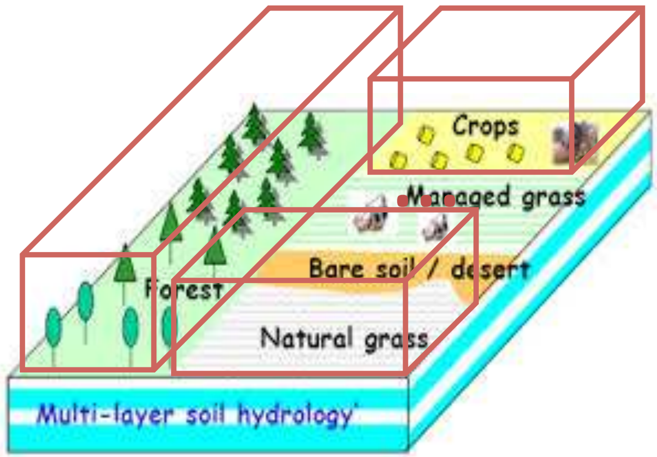


Why PFT-specific water & energy budget needed?

CASE A (default)

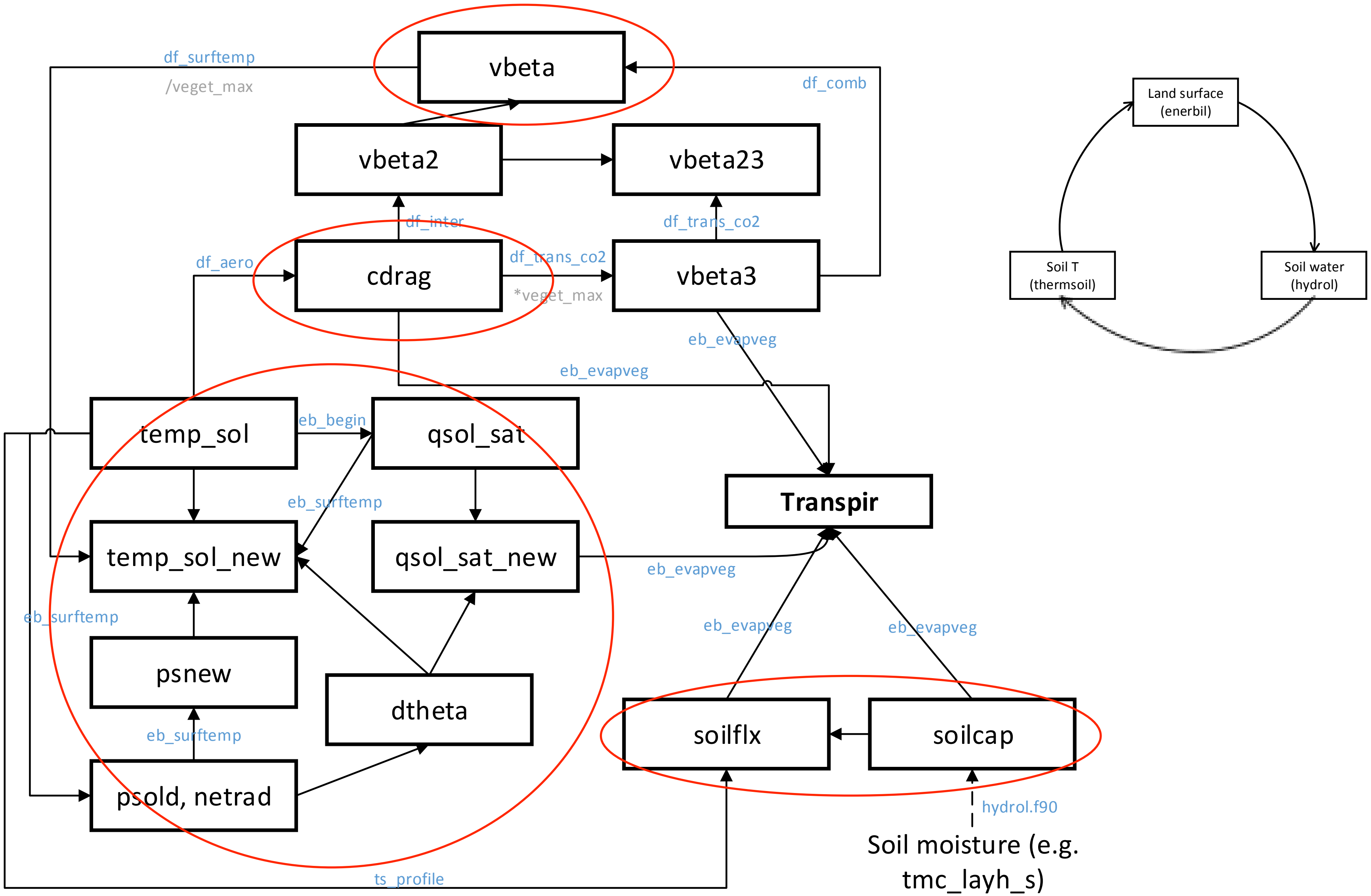


CASE B



Croplands usually applies to Case B, which is not previously supported

The variables made PFT-specific



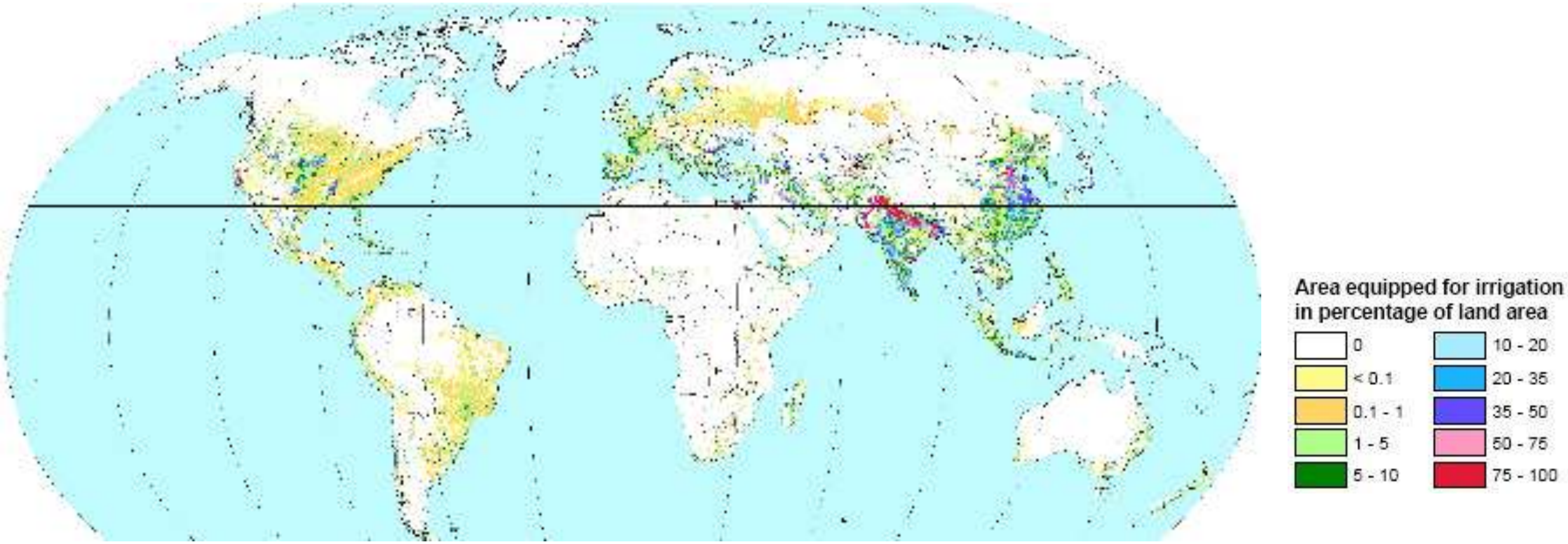
Abbreviations: eb_ = enerbil_ , df_ = diffuco_ , ts_ = thermosoil_

Lists of sub-modules

- Growth dynamics
  - Phenology
  - Allocation

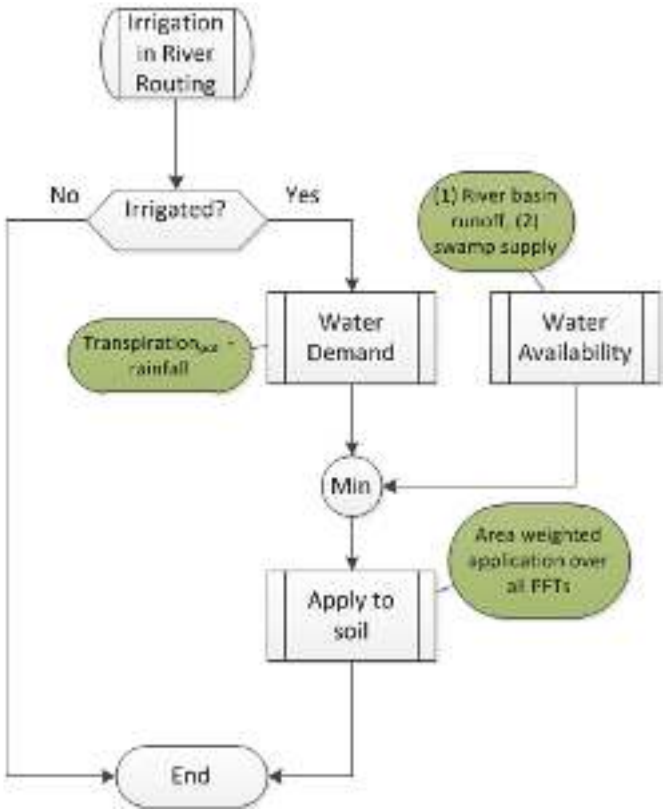
- **Managements**
  - **Irrigation**
  - **Fertilization**
  - **Rotation**
  - **Residue management**

Global irrigation extent



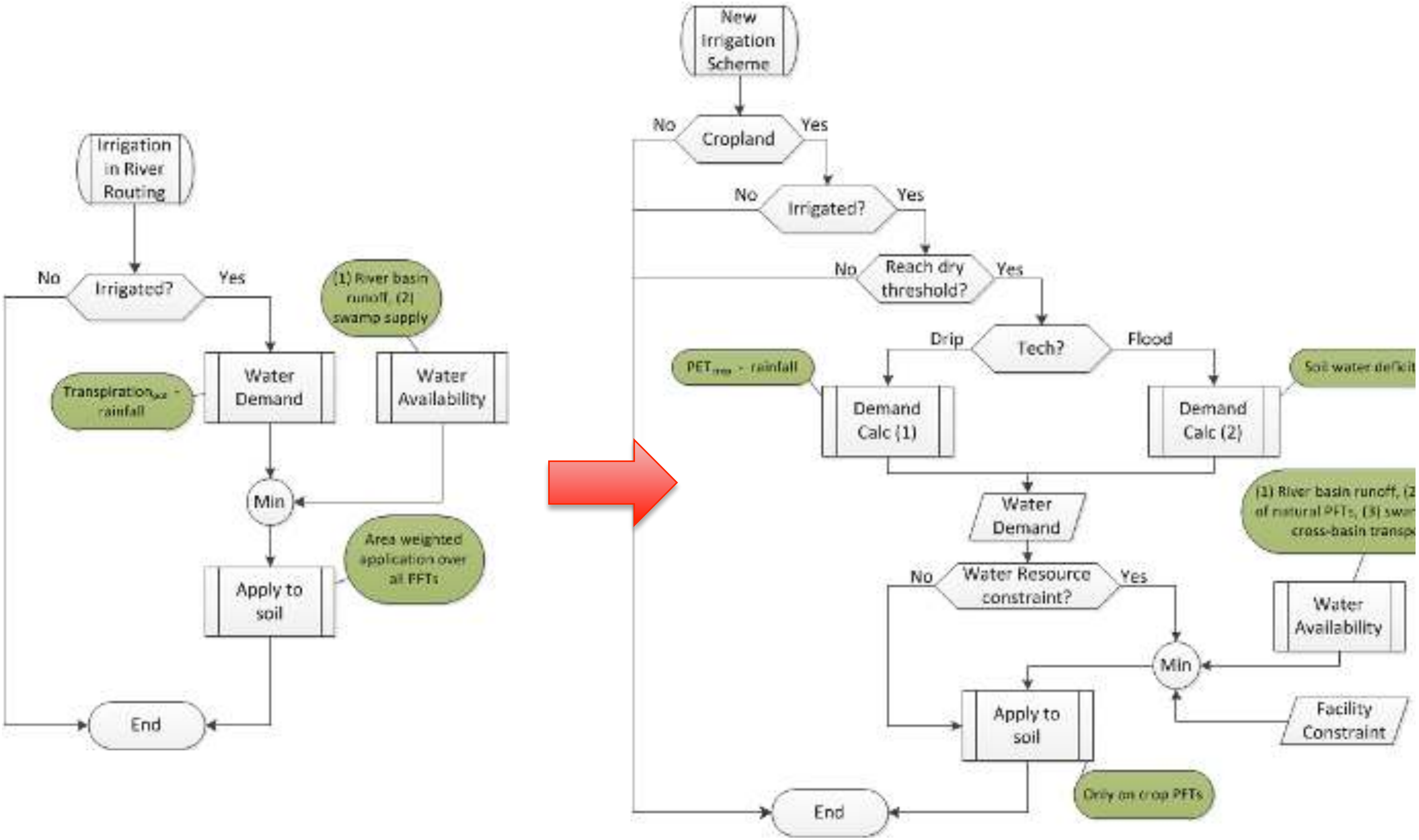
Courtesy from GMIA v5

ORCHIDEEstandard irrigation scheme



- Limitations:
  - Only activated with river routing
  - Water demand & applications over all PFTs
  - Considering only potential transpiration, not PET (always deficit even irrigated)
  - no room for varying irrigation technologies/strategies

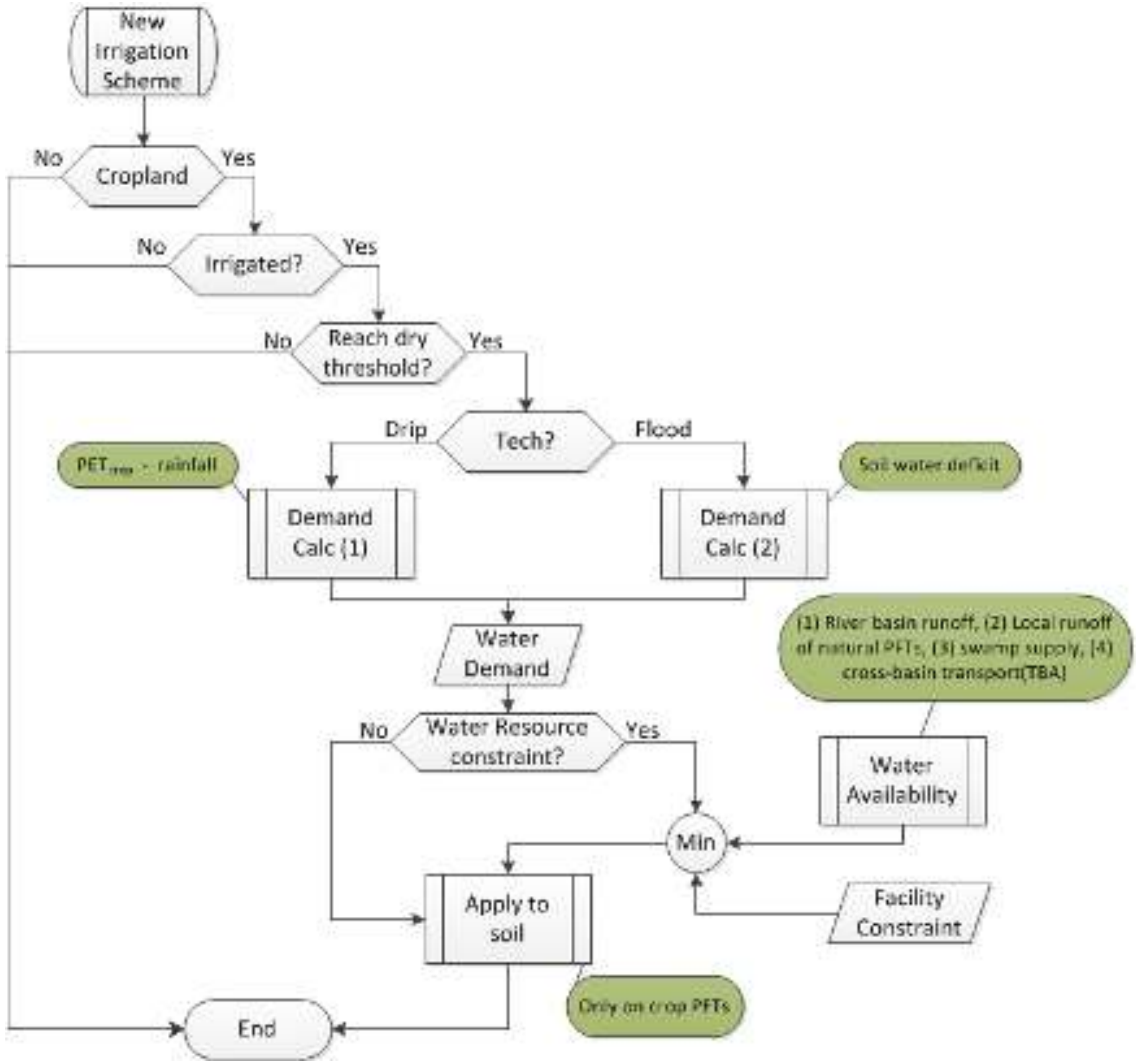
Solution?



Irrigation in River Routing
Irrigated?
No
Yes
Transpiration - rainfall
Water Demand
(1) River basin runoff, (2) swamp supply
Water Availability
Min
Area weighted application over all PFTs
Apply to soil
End
New Irrigation Scheme
Cropland
No
Yes
Irrigated?
No
Yes
Reach dry threshold?
No
Yes
Tech?
Drip
Flood
PET - rainfall
Demand Calc (1)
Demand Calc (2)
Water Demand
Water Resource constraint?
No
Yes
Water Availability
Min
Facility Constraint
Apply to soil
Only on crop PFTs
End

ORCHIDEEcrop irrigation scheme

- Addressing:
  - Where?
  - When?
  - How much?
  - How?



Irrigation methods & Tech constraints (how)

Some key parameter: IRRIG_DRIP, IRRIG_DOSMAX

Flooding

- Demand = Soil water deficit (irrig_fulfill * SWHC - SWC)

SWHC: soil water holding capacity
SWC: soil water content

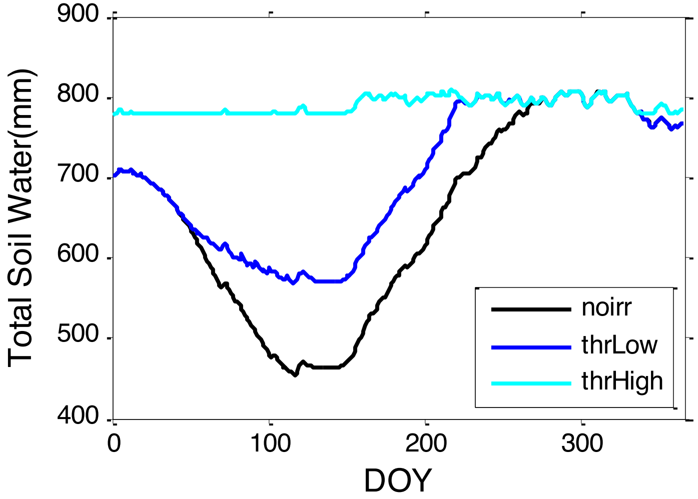
Drip

- Demand = PET_{crop} - rainfall

When?

Key parameter: IRRIG_THRESHOLD

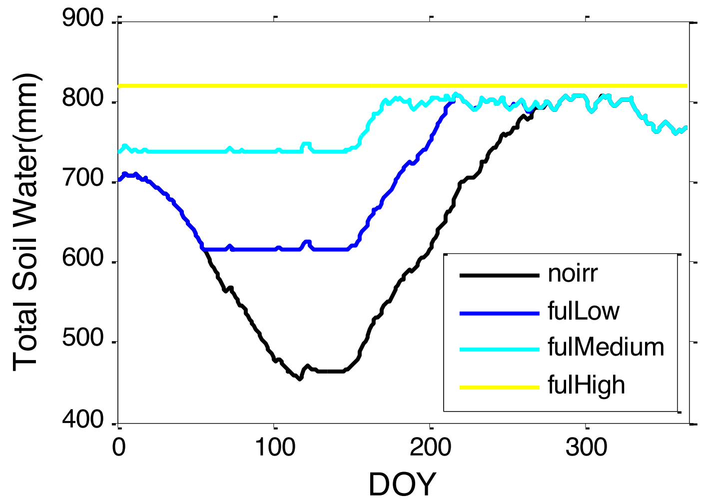
Threshold (% of vegetation growth stress)
to which we start irrigation



How much?

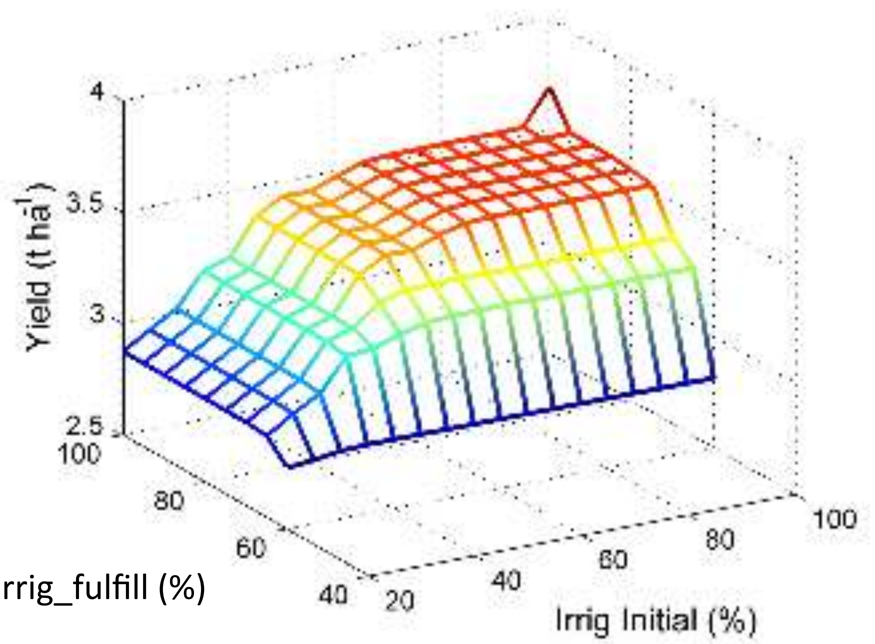
Key parameter: IRRIG_FULFILL

Threshold (% of soil water holding capacity) to which we saturate the soil

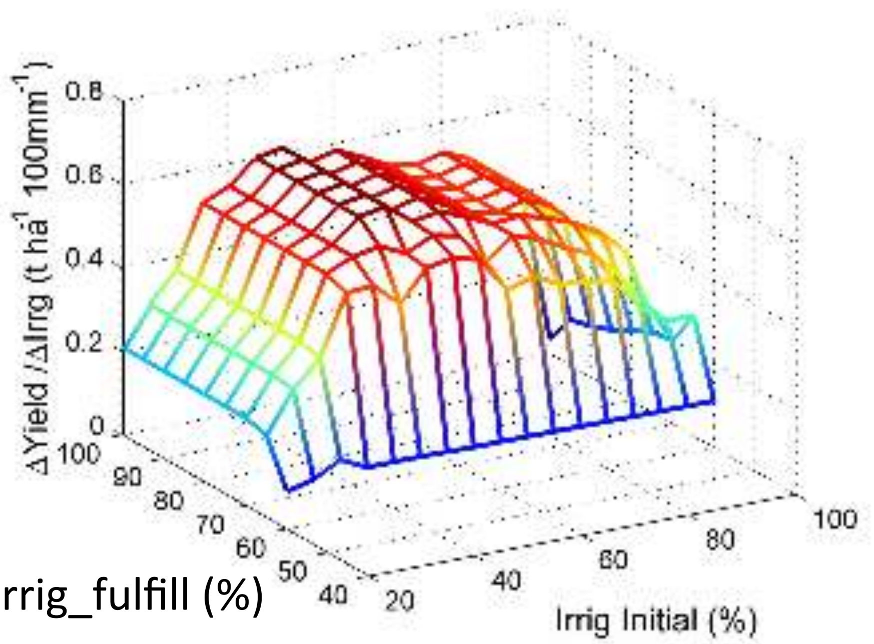


Irrigation response functions

Yield ~ irrigation



Irrigation Efficiency ~ irrigation



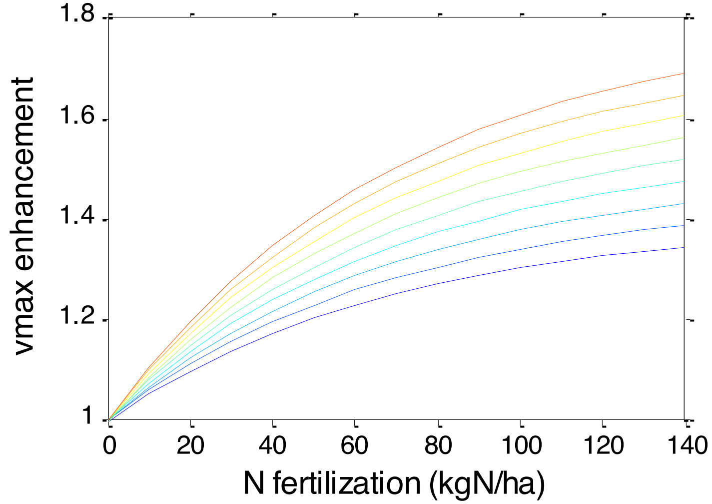
Irrigation Efficiency (t/ha/100mm) = dYield/dIrrigationWater

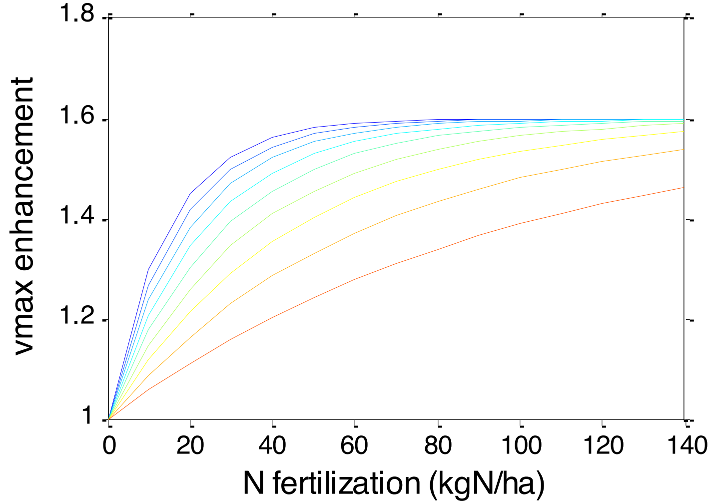
N response function

- Nfac = 1 + Neff - Neff*(pa^(Nfert./pb));

- Three parameters to optimize:
  - Neff (maximum enhancement of N fertilizer)
  - pa (how fast the N response saturated)
  - Vcmax25 (intrinsic Vcmax at 25 ^{o}C)

fertilization





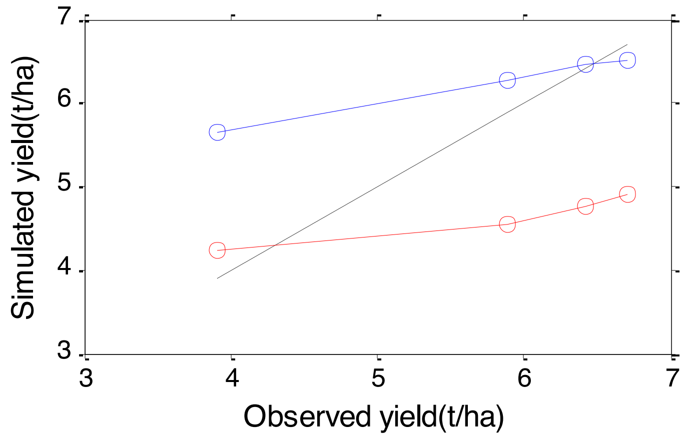

```
NITROGEN_USE = y
FIX_NFERT = y
SP_AVENFERT = 0.0, 0.0, 0.0, 10.0, 10.0, 10.0
NEFFMAX=0, 0, 0, 0.65, 0.65, 2.51
NSATRAT=0, 0, 0, 0.91, 0.91, 0.68
VCMAX25=40, 70, 70, 70, 70, 46.2

##NFERT_FILE = /home/satellites8/speng/Xuhui/data/Fert_IFA_FAO.nc
##NFERT_FILE = /home/satellites8/speng/Xuhui/data/Fert_ISIMIP_harm.nc
```

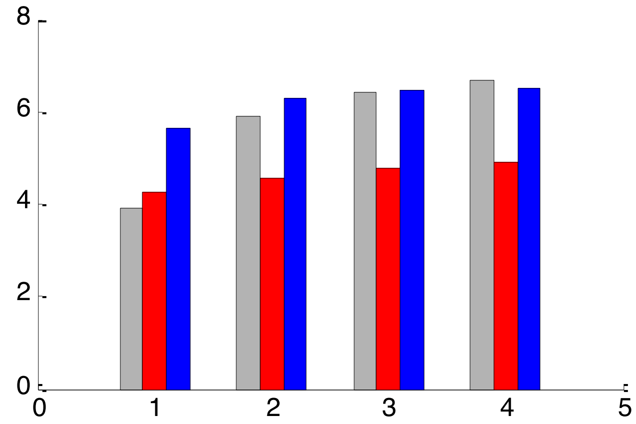
opt1

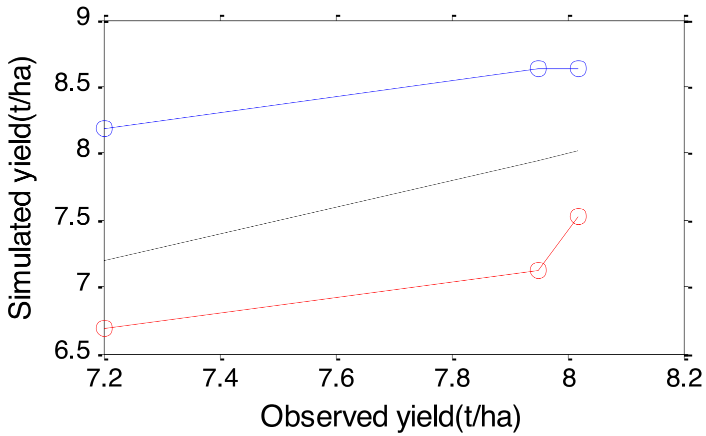
Constrain
Vcmax25>40

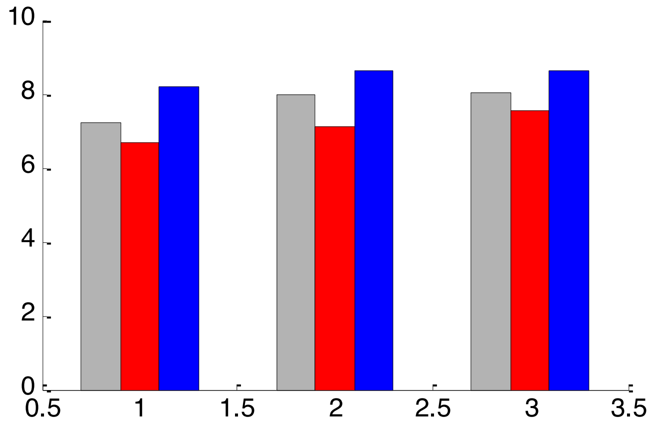
Prior set:
Neff 0.65
Pa 0.91
Vcmax25 70

Posterior set:
Neff 2.51
Pa 0.68
Vcmax25 46.2







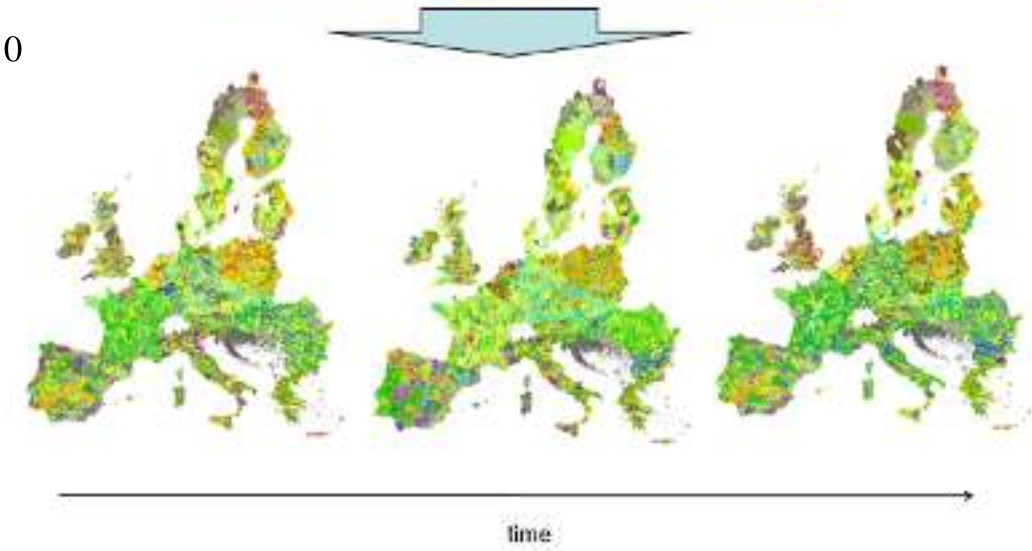


Crop rotation/multi-cropping

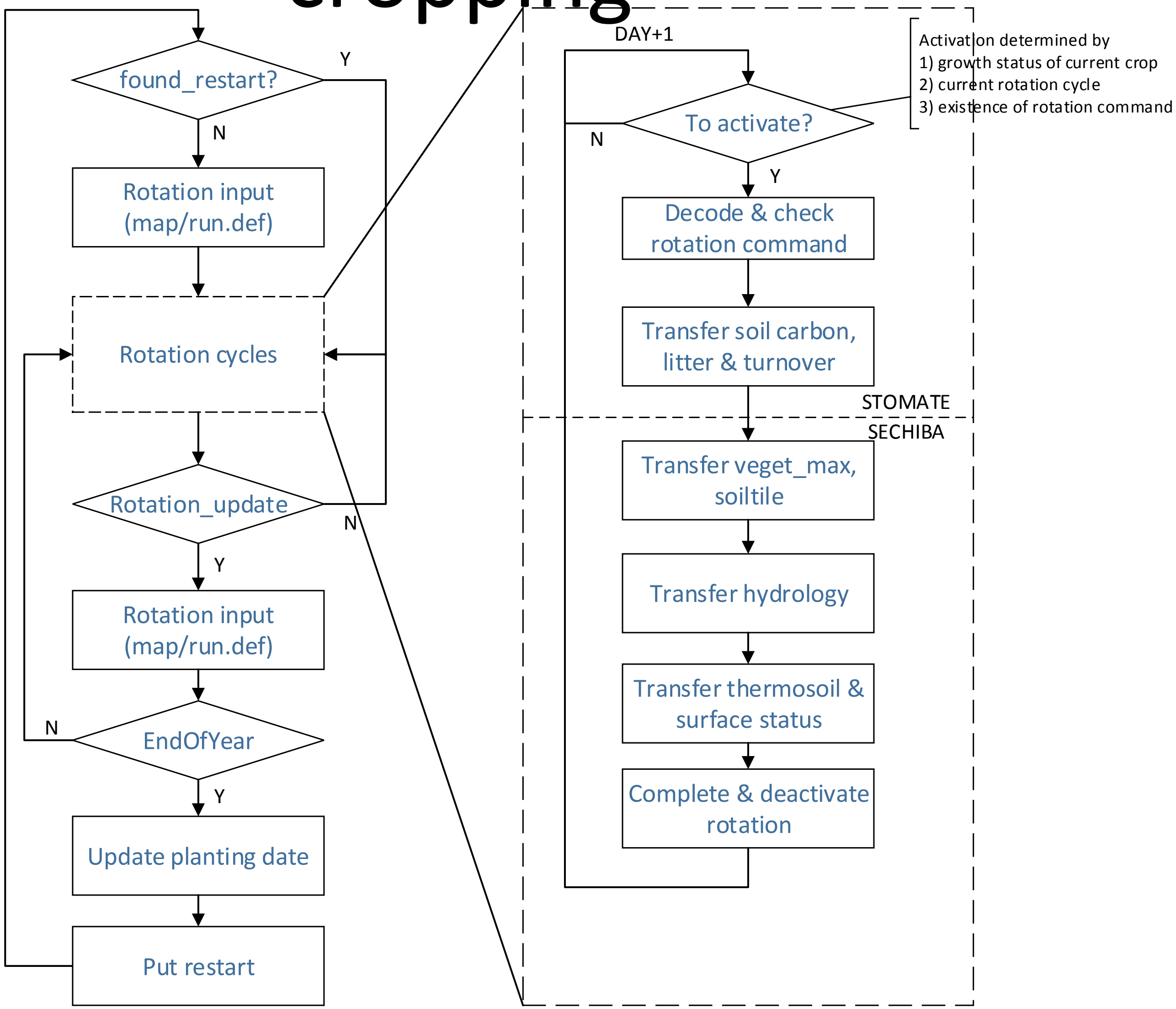
time

Germany	Greece	Italy	Espania	United King.	Poland
POTA	PULS	DWHE	RAPE	RAPE	WBAR
WRYE	WBAR	WSWH	WBAR	OATS	RAPE
MAIZ	MAIZ	MAIZ	MAIZ	SETA	WRYE
WRYE	WBAR	WSWH	SUNF	SBAR	OCER
MAIZ	MAIZ	MAIZ	WBAR	SETA	SBAR
SBAR	WBAR	WSWH	MAIZ	SBAR	WRYE
RAPE	MAIZ	MAIZ	SUNF	RAPE	MAIZ
WRYE	WBAR	PARI	WBAR	SBAR	SSWH
MAIF	MAIZ	SETA	RAPE	SETA	MAIZ
WRYE	WBAR	MAIZ	WBAR	SBAR	SSWH
MAIF	MAIZ	WSWH	MAIZ	SETA	MAIZ
POTA	WBAR	MAIZ	SUNF	SBAR	SSWH
SBAR	MAIZ	WSWH	WBAR	RAPE	MAIZ
RAPE	POTA	MAIZ	RAPE	WBAR	SSWH
WRYE	MAIZ	WSWH	WBAR	SETA	MAIZ
MAIF	WBAR	MAIZ	MAIZ	SBAR	SSWH
WRYE	MAIZ	WSWH	SUNF	SETA	MAIZ
MAIF	WBAR	MAIZ	WBAR	SBAR	SSWH
WSWH	MAIZ	WSWH	MAIZ	RAPE	MAIZ
RAPE	POTA	MAIZ	SBAR	WBAR	SSWH
WSWH	MAIZ	WSWH	RAPE	PULS	MAIZ
MAIF	WBAR	MAIZ	WBAR	WBAR	SSWH
WSWH	MAIZ	PARI	SUNF	PULS	POTA
MAIF	WBAR	SETA	SBAR	WBAR	WRYE
WSWH	MAIZ	MAIZ	SUNF	RAPE	OCER
WRYE	POTA	PARI	SBAR	WBAR	SSWH
MAIF	MAIZ	SETA	RAPE	PULS	SUGR
SBAR	WBAR	MAIZ	WBAR	WBAR	SSWH
RAPE	MAIZ	WSWH	SUNF	PULS	POTA
MAIF	WBAR	MAIZ	SBAR	WBAR	WRYE

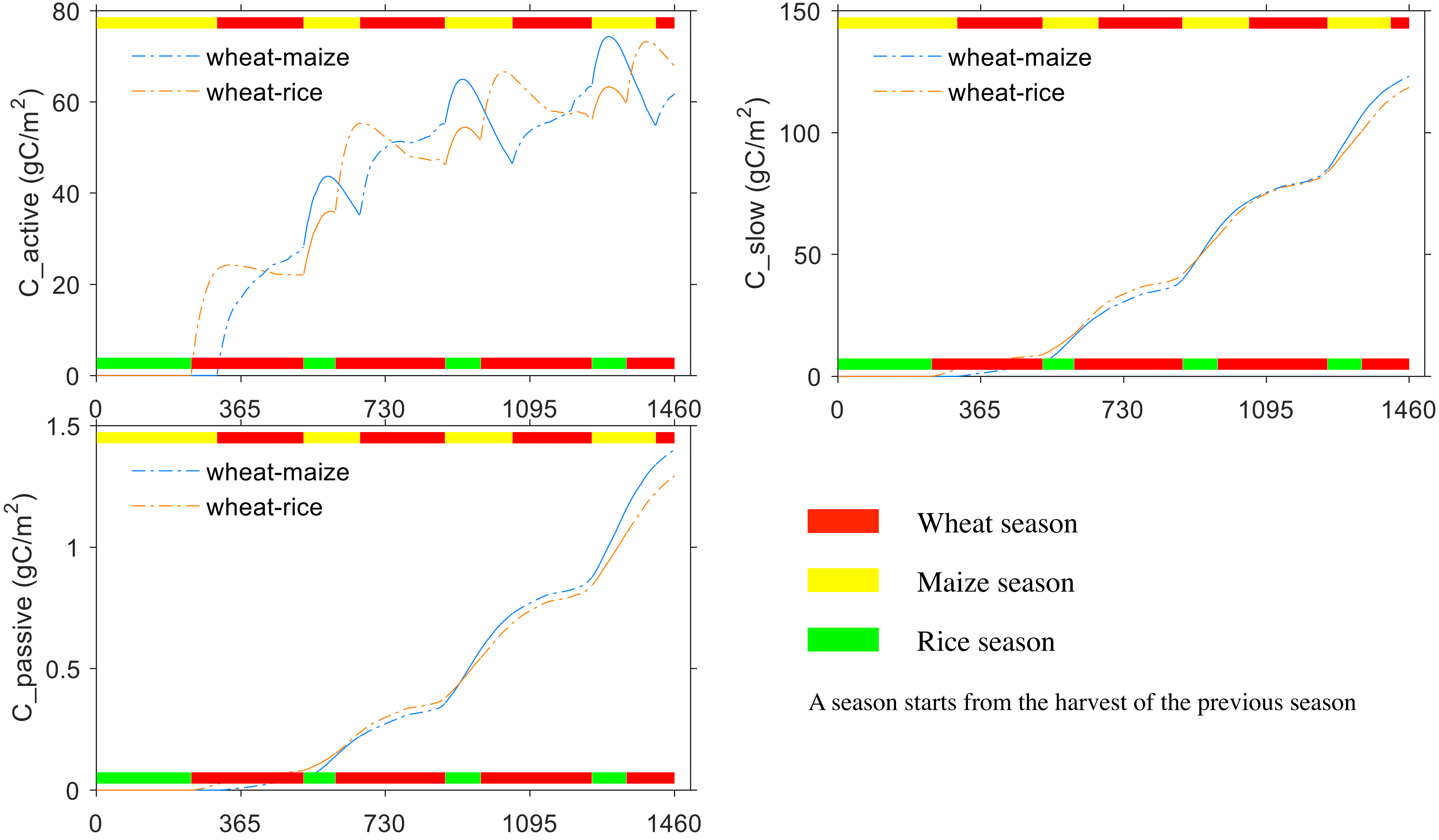
Wattenbach et al., 2010



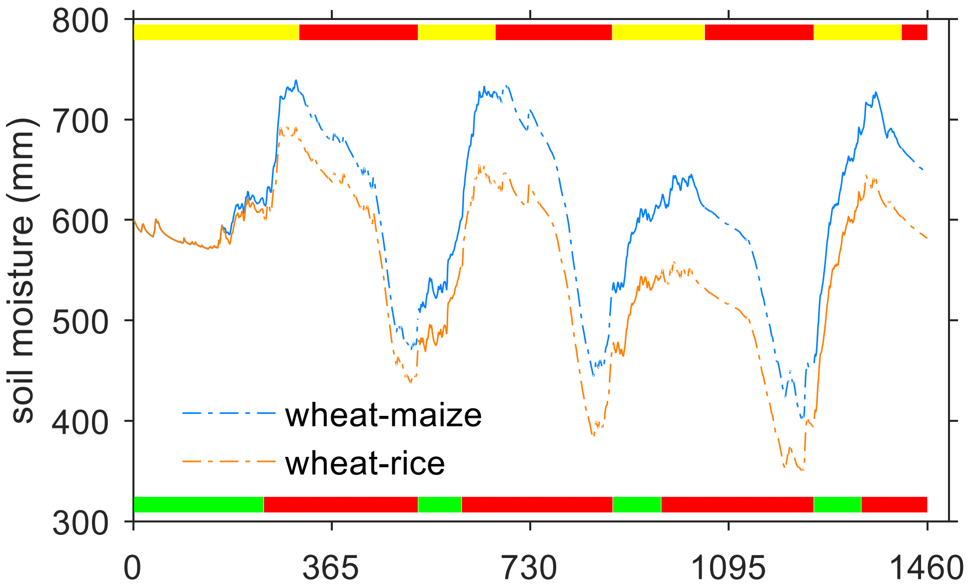
The flowchart for crop rotation/multi-cropping

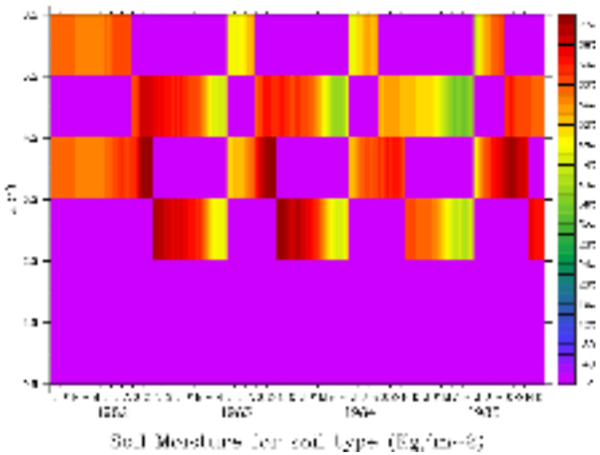


Transfer of litter & soil carbon pools



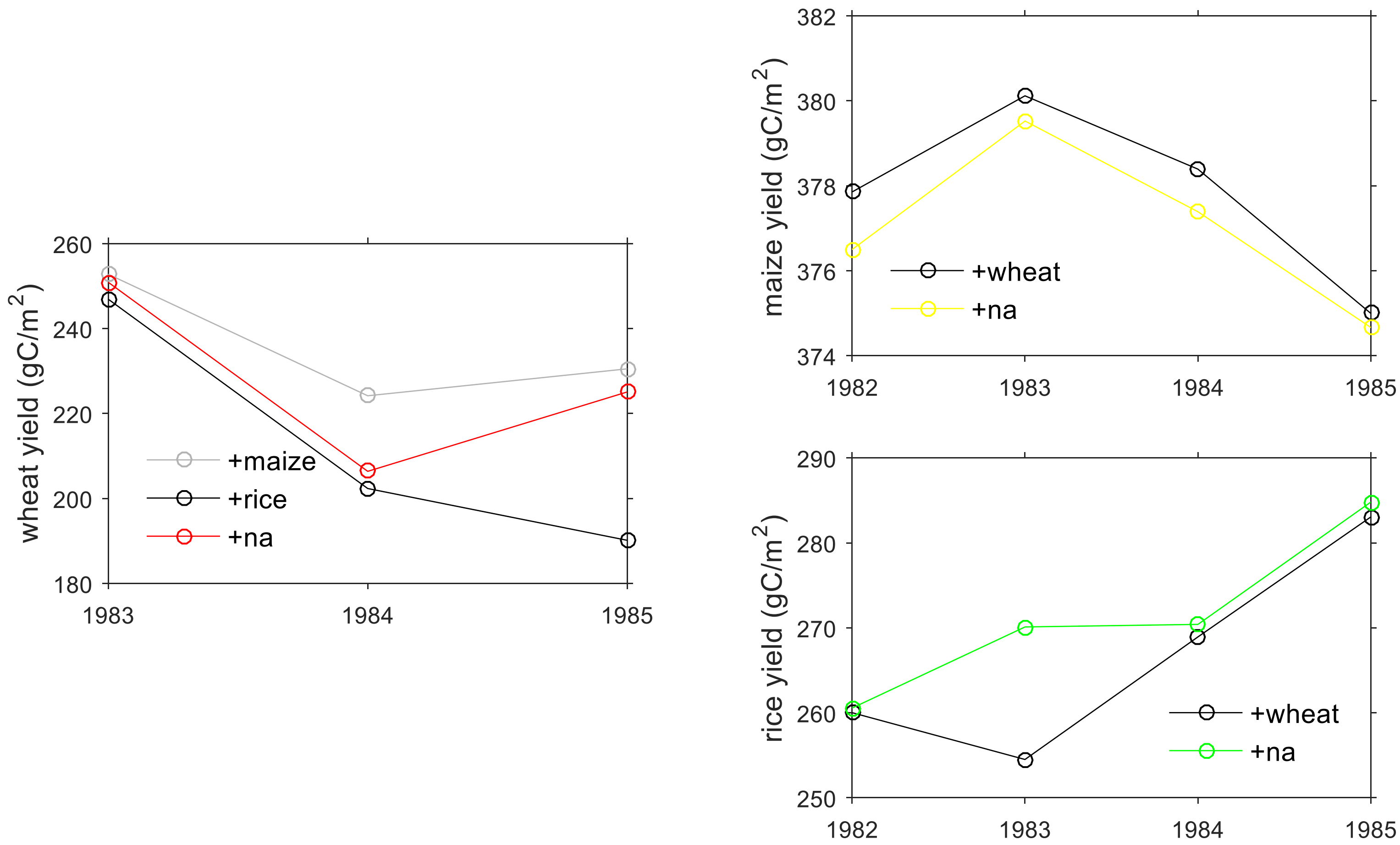
Transfer of soil moisture



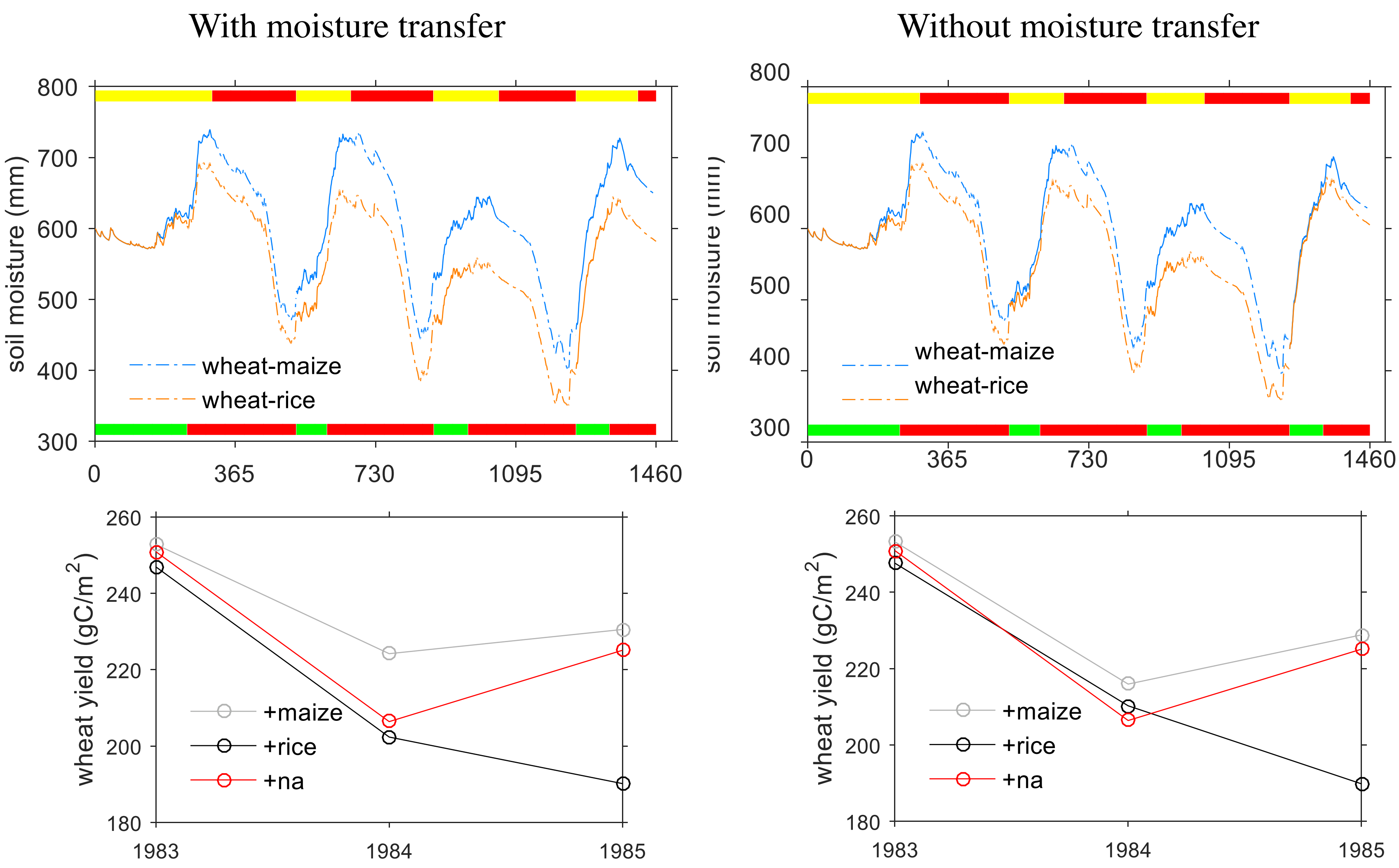


Variables transferred in SECHIBA,
Transferred status variables: veget_max, soiltile
Transferred hydrology variables: moisture of all layers & water to infiltrate next time step
Transferred thermal variables: soil temperature of all layers & conductivity (cgrnd, dgrnd)
Other variables: surface soil temperature (temp_sol_new), heat capacity (soilcap) and heat flux (soilflx)

Yield, multiple vs. single cropping



w/ or w/o soil moisture transfer



The data structure

Transfer matrix → Command list

src \ dest	1	2	3	4	5	6	7	8
1								
2								
3								
4								
5						50		
6								
7								
8							80	

An integer (i_std, int32) with 7 meaningful digits:

% transfer			source		target	
1	0	0	0	9	1	0

e.g.
500506
800807

Note:
By using percentage transfer, the RMC module is in theory compatible with the LUC module of ORCHIDEE i.e. RMC & LUC can be activated simultaneously (to be tested)

Configuration for rotation

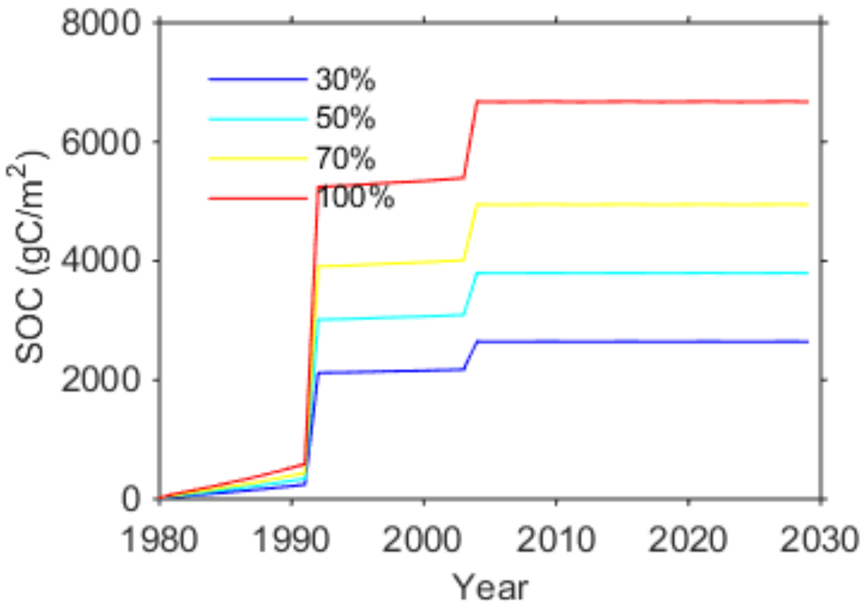
1D

- Planting date for each crop-rotation cycle:
  - SP_IPLT0 = 0, 0, 0, 310, 160, 310, 161
  - SP_IPLT1 = 0, 0, 0, 310, 160, 310, 161
  - NVM_PLNT = y (NVM or MTC PFT)
- No. of rotation cycles:
  - CYC_ROT_MAX = 2
- Rotation command for each cycle:
  - CMDROTATE_1 = 1000504, 1000706, 0
  - CMDROTATE_2 = 1000405, 1000607, 0
- If the planting date needs to be changed within a rotation cycle:
  - DYN_PLNTDT = y
- If rotation system needs to be updated:
  - ROTATION_UPDATE = 10Y

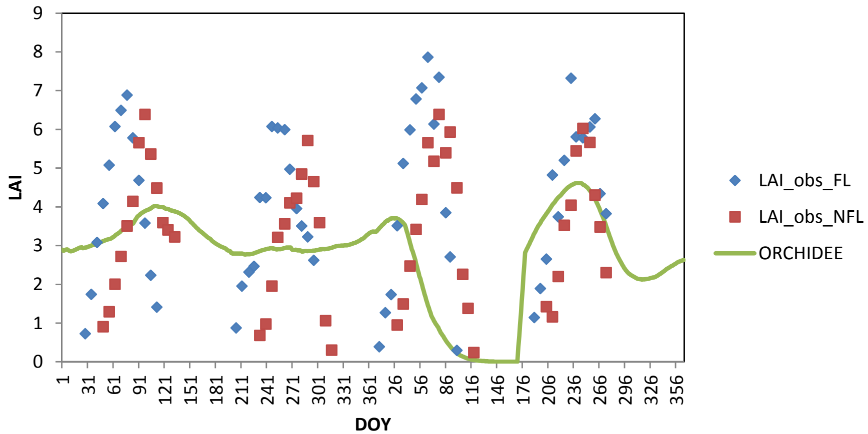
2D

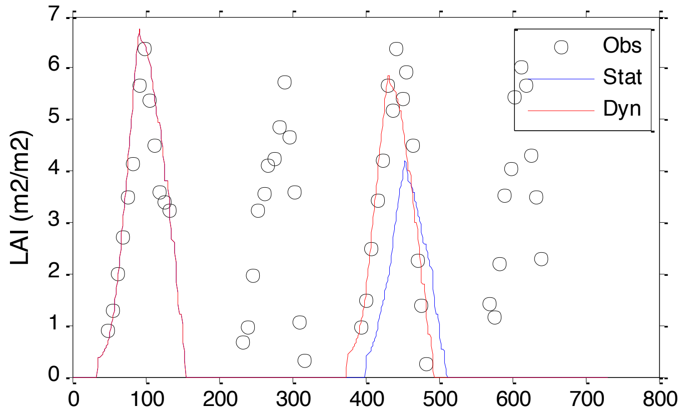
- Planting date for each crop-rotation cycle:
  - IPLT_FILE = iplt.nc
- No. of rotation cycles in each grid:
  - NUMROTATE_FILE = filename1.nc
- Rotation command of each grid:
  - CMDROTATE_FILE = filename2.nc
- Others
  - DYN_PLNTDT & ROTATION_UPDATE can also be set for update frequencies of rotation systems and crop planting date with new maps

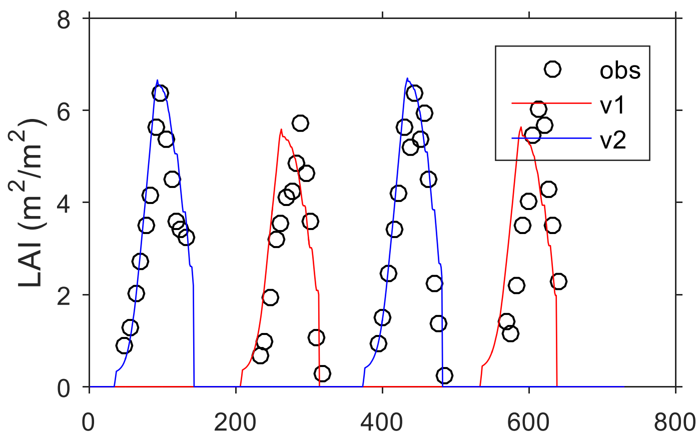
Residues management



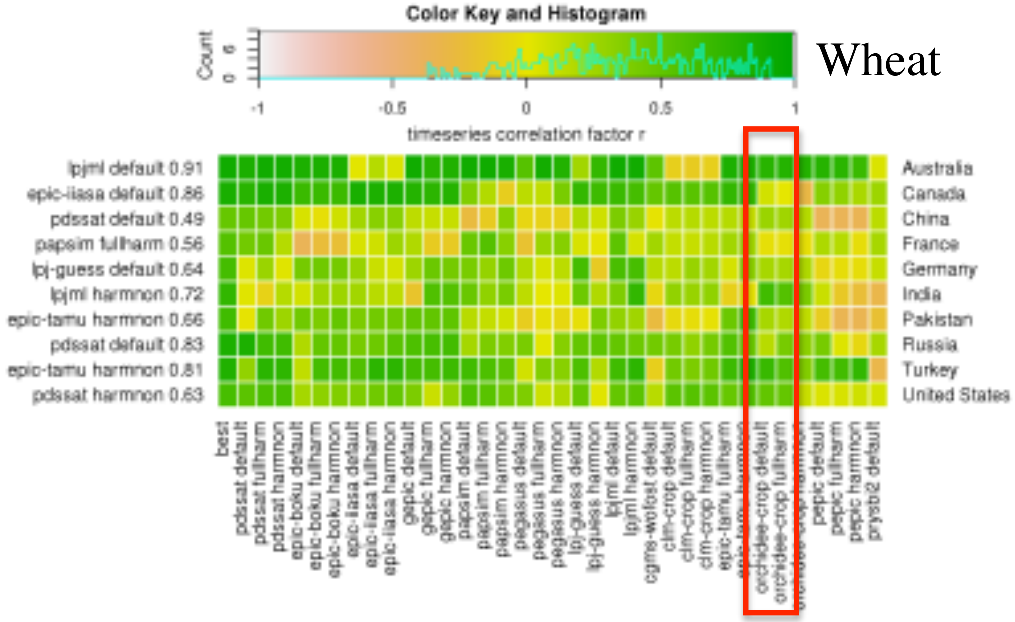
IRRI site (14.2ºN, 121.3ºE)

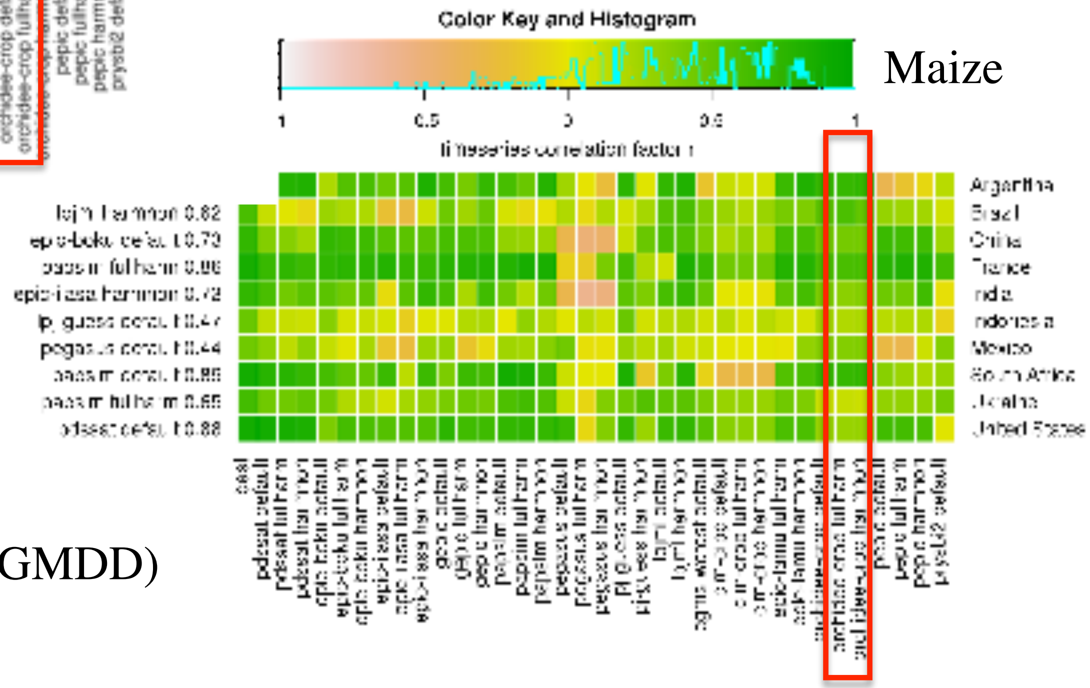






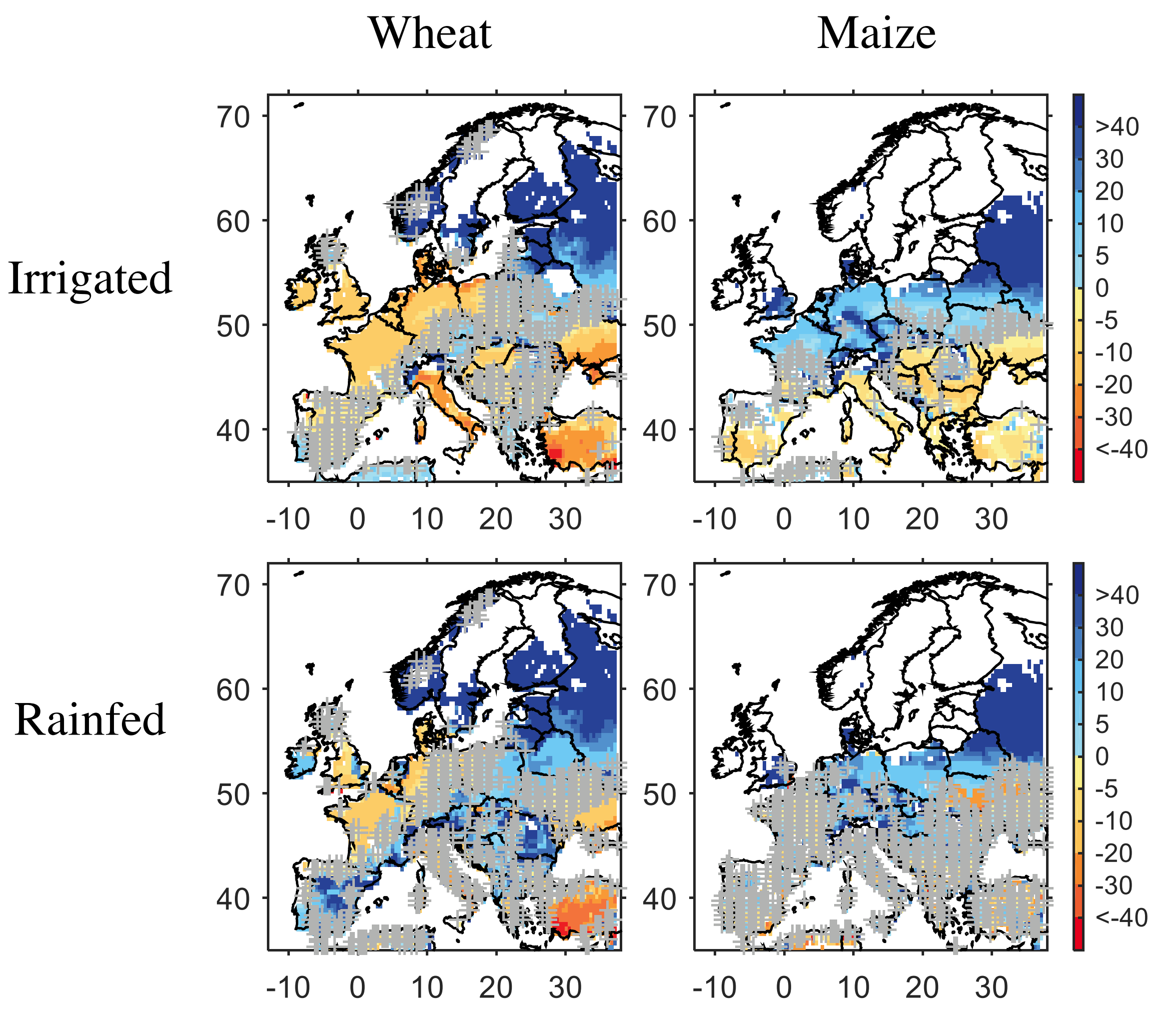
Model Evaluation





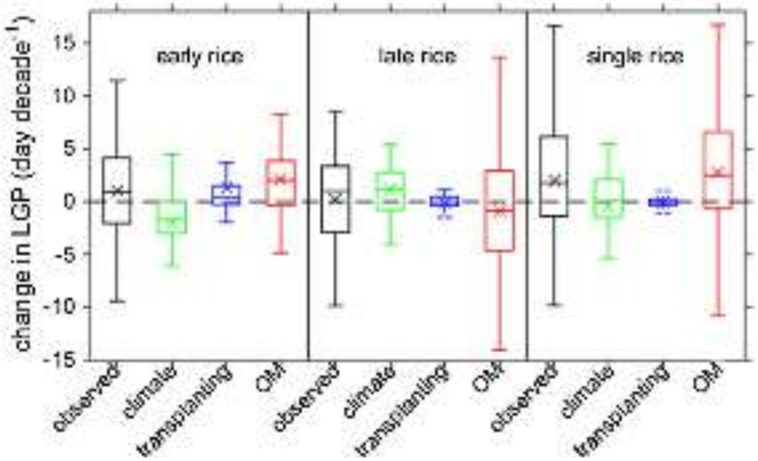
(Muller et al., 2016 GMDD)

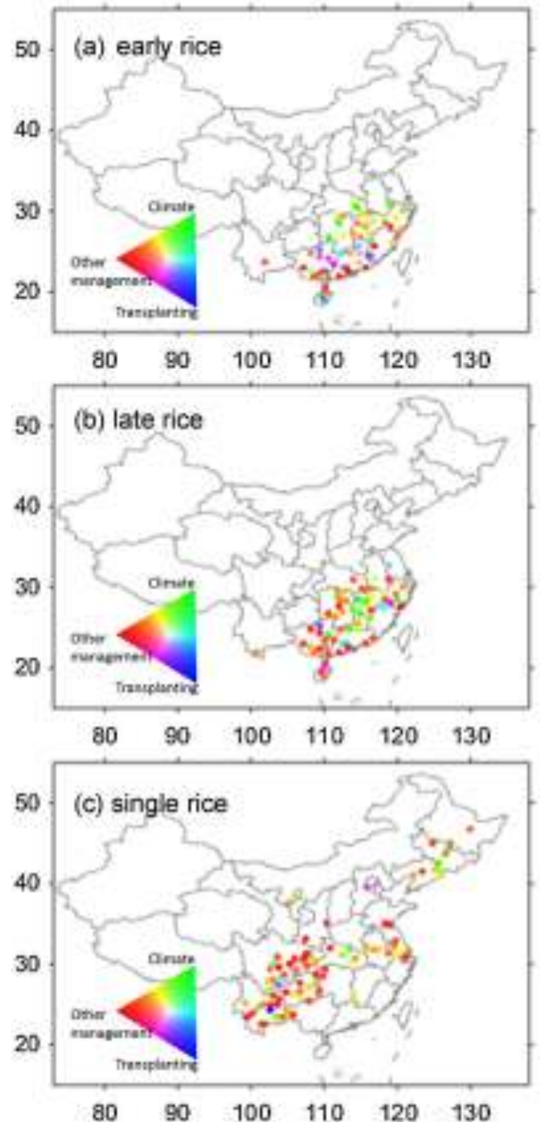
Impact of climate change on European cropland



- The impact of 4K warmer climate on European croplands (HELIX)
- The impact of 2K warmer climate on European croplands (IMPACT2C)

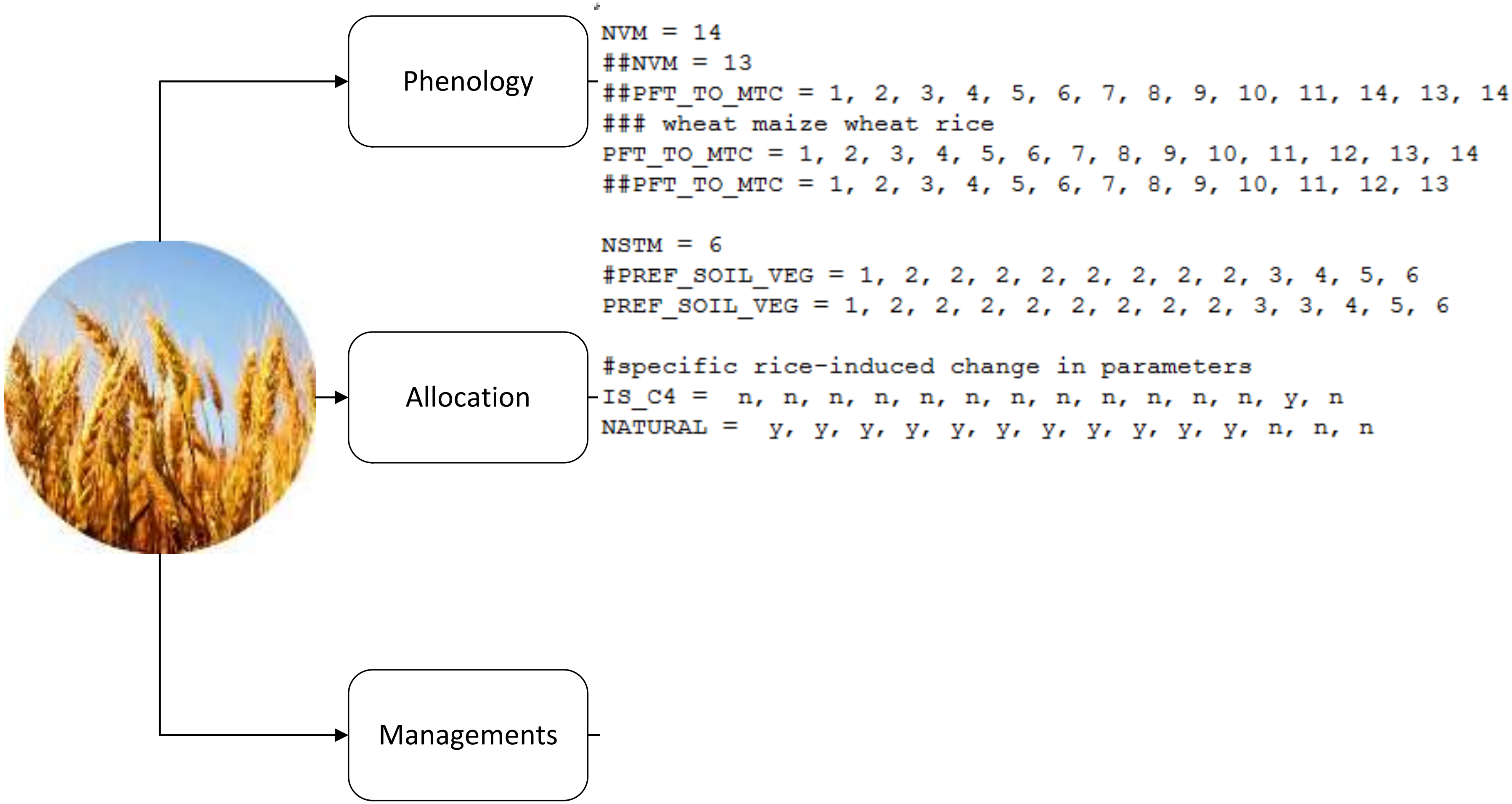
Detection & attribution



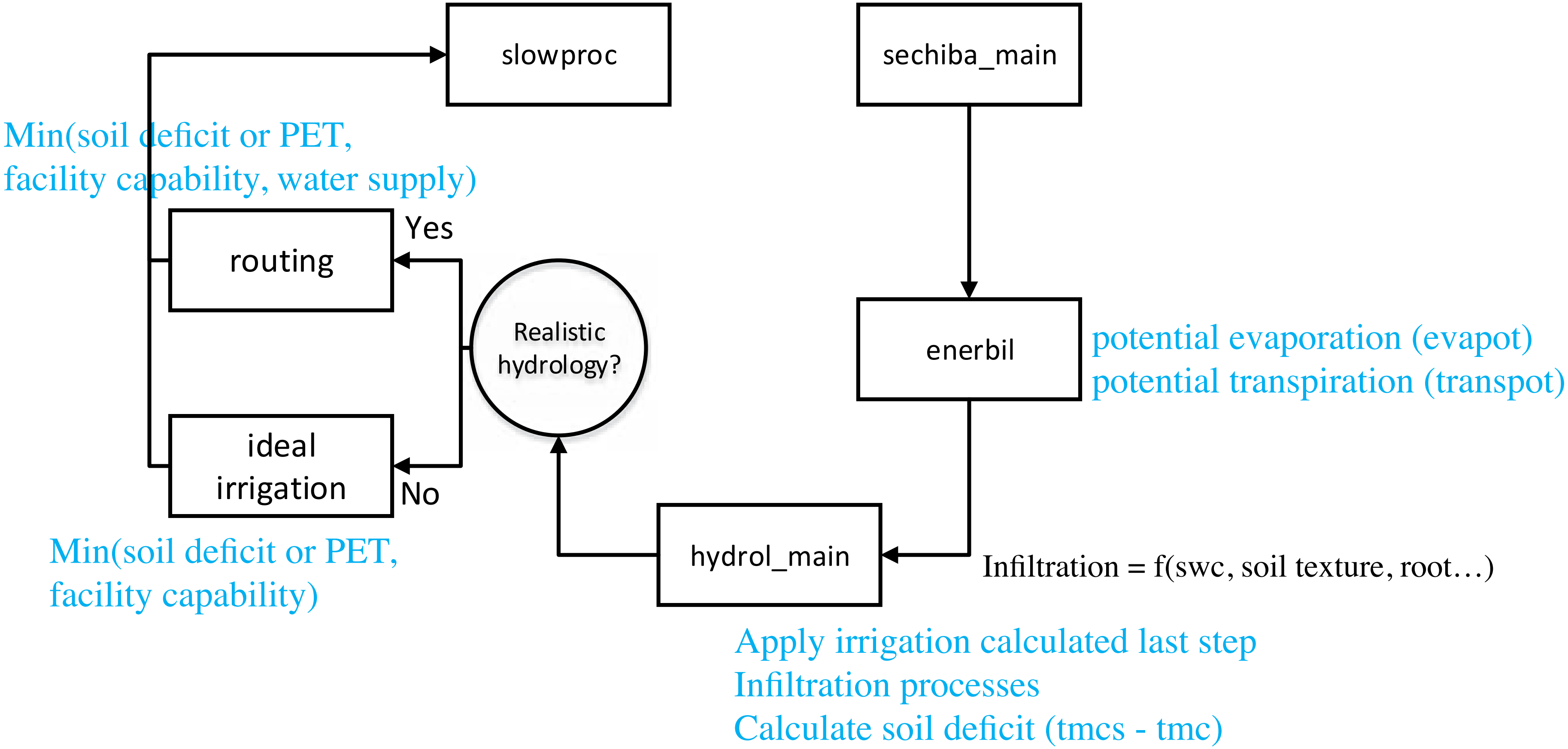


(Wang et al., 2017 AFM)

Thanks for your attention ☺


Phenology
Allocation
Managements
NVM = 14
##NVM = 13
##PFT_TO_MTC = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 13, 14
wheat maize wheat rice
PFT_TO_MTC = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
##PFT_TO_MTC = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
NSTM = 6
#PREF_SOIL_VEG = 1, 2, 2, 2, 2, 2, 2, 2, 2, 3, 4, 5, 6
PREF_SOIL_VEG = 1, 2, 2, 2, 2, 2, 2, 2, 2, 3, 3, 4, 5, 6
#specific rice-induced change in parameters
IS_C4 = n, n, n, n, n, n, n, n, n, n, n, n, y, n
NATURAL = y, y, y, y, y, y, y, y, y, y, y, n, n, n

On the SECHIBA

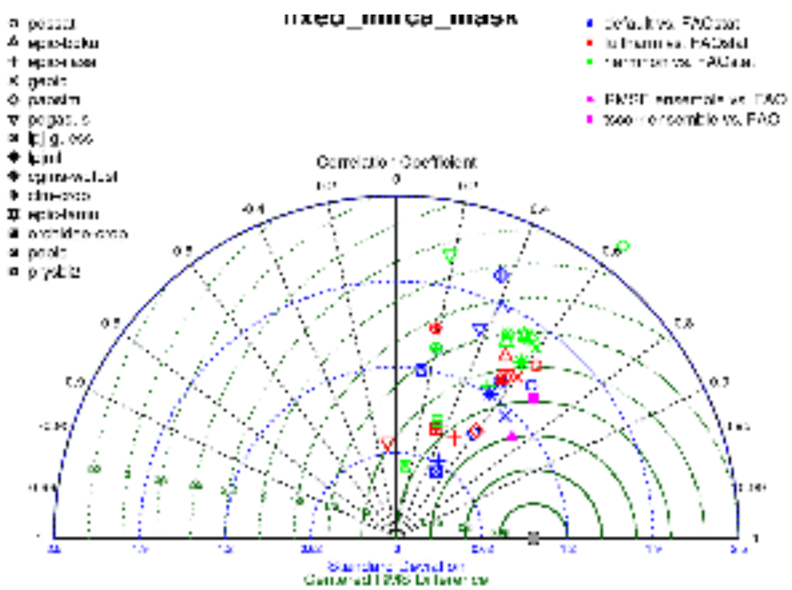


For run.def
DO_FULLIRR

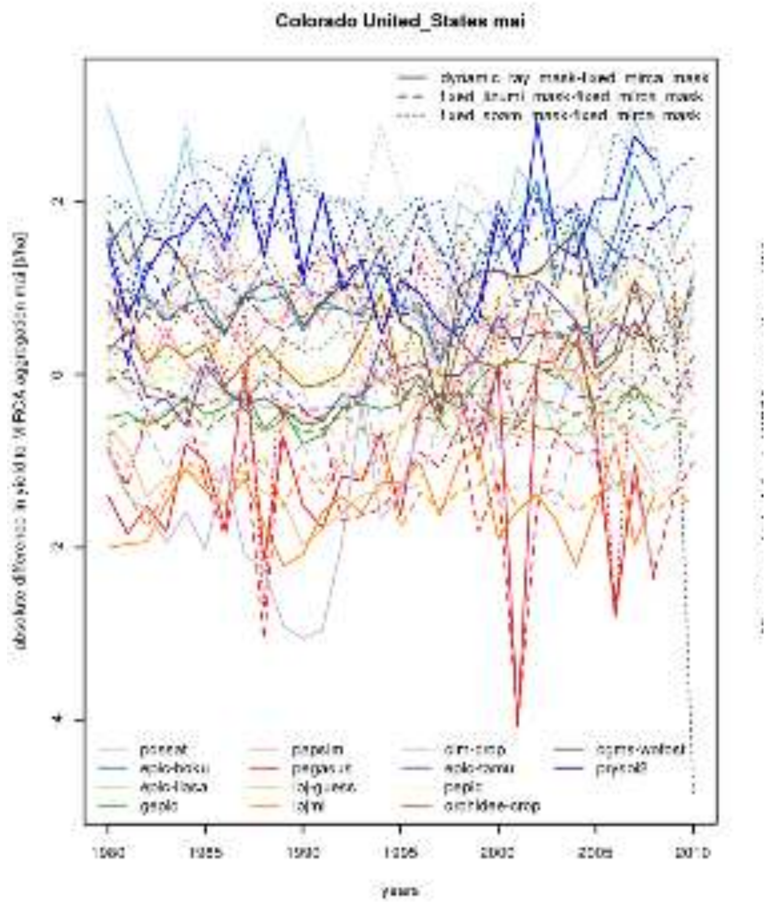
tmc: total column moisture content
tmcs: total column moisture content when saturated

AgMIP The Agricultural Model Intercomparison and Improvement Project

Global gridded crop models



Model evaluations (Muller et al., 2016 GMD)



Porwollik et al., 2016 EJA