Co-design of Gene-based Ecophysiological Crop Models for Breeding and Management

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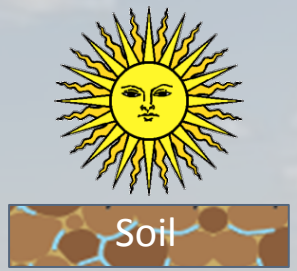
Reasons for needing new methods

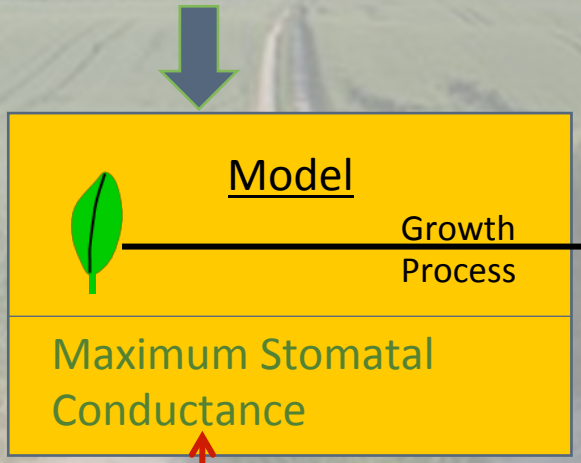
- Crop models are central to achieving the annual rates of gain required for mid-century food security
- The key reason – they handle GxExM interactions concisely and with noteworthy accuracy
- **However**, crop models currently:
  - Have mathematical structures resistant to proper calibration & estimation of variability
  - Do not reflect advances in high throughput sensing
  - Do not adequately relate to genetic elements

Inferring phenotypes…



Environmental Data

Leaf Area Phenotype



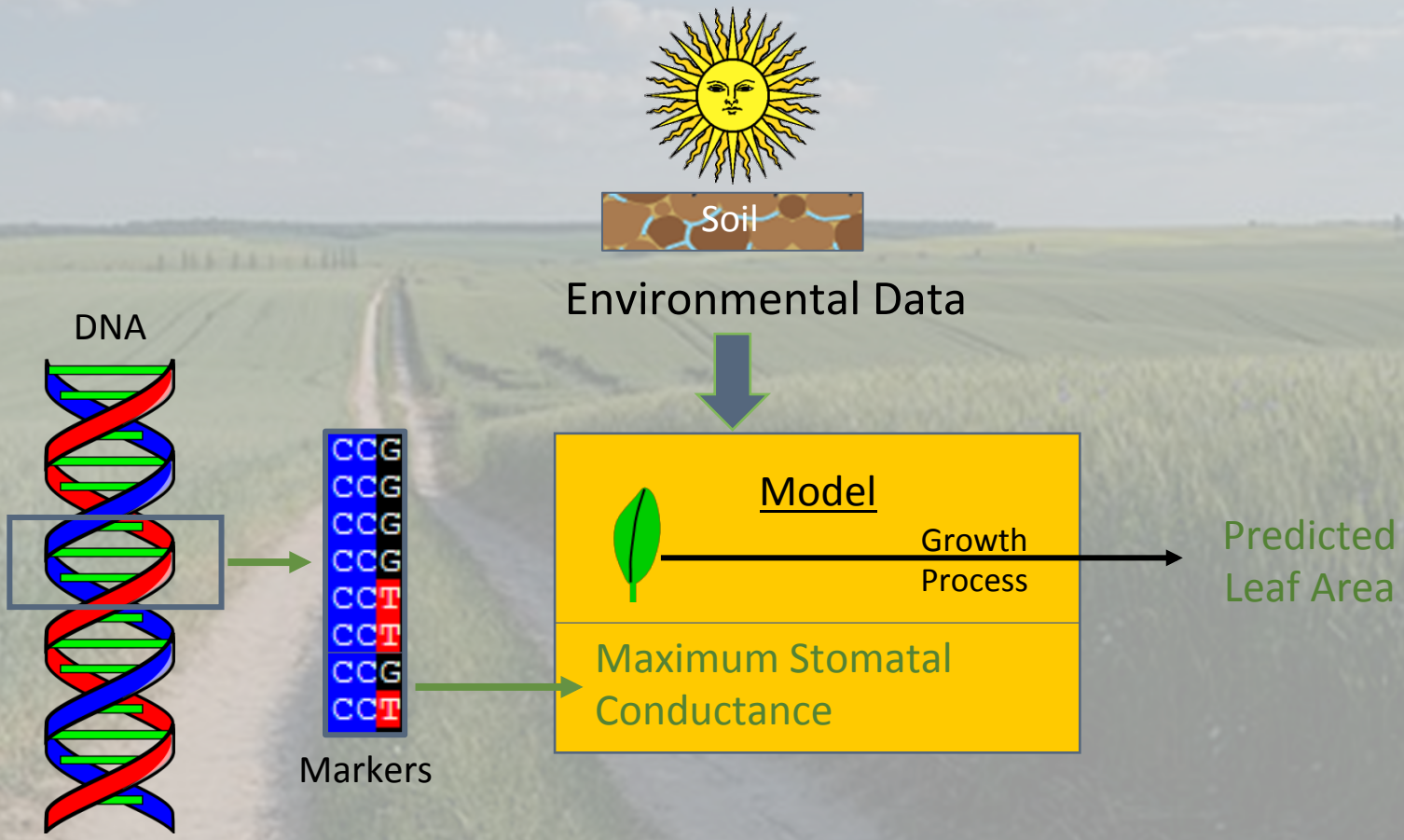
Predicted

Estimated

Observed

Optimizer: Adjust this so this agrees with this

But what we really want is…

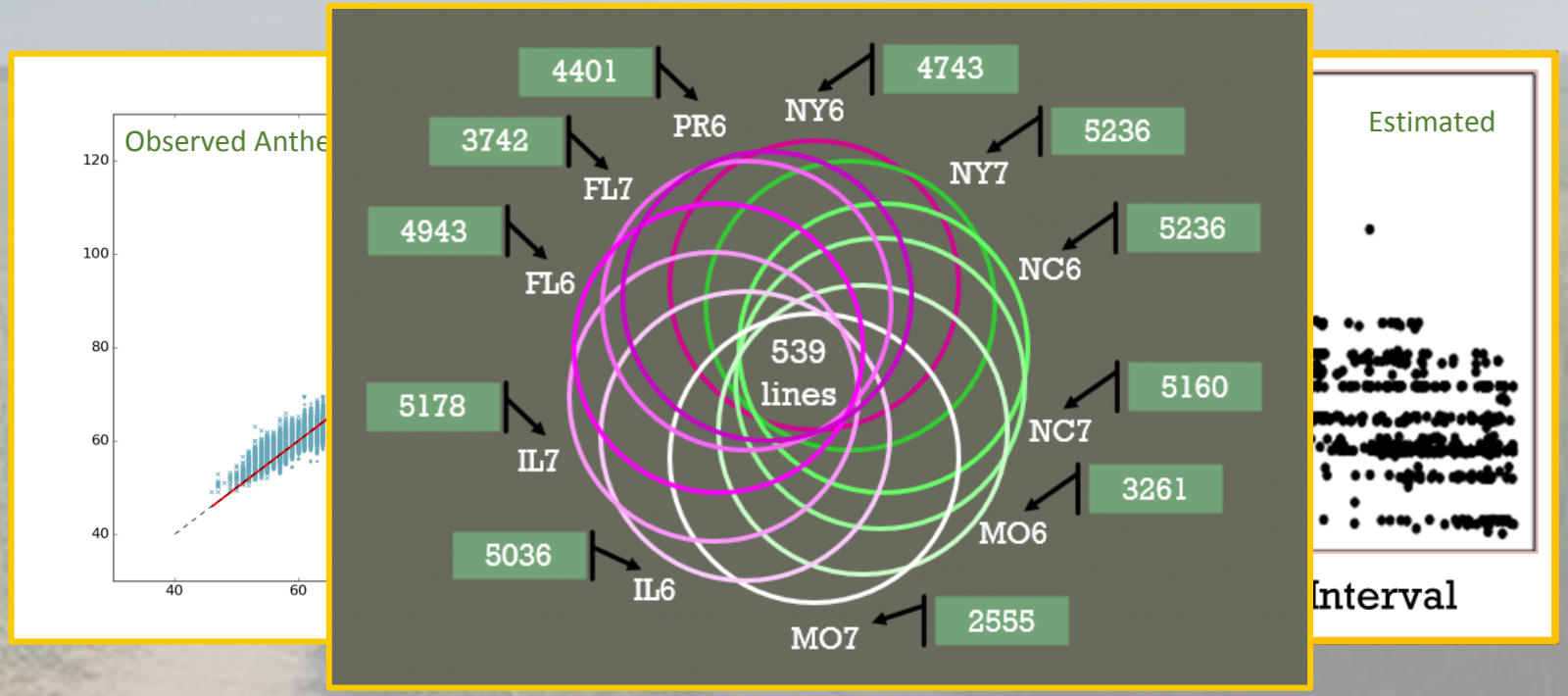


The road in that direction…

- Two general approaches
  - Ma et al. 2003. Genetics 161(4):1751-1762.
    - Simple growth curves; QTL-based
  - Hammer et al. 2006. Trends Plant. Sci. 11:587-593.
    - Wider class of models; extends to genomic prediction
- Between them, they have been cited 524 times and those papers have 10,092 cites
- Both involve parameter estimation…
- …but significant issues have emerged

A study with surprising results…

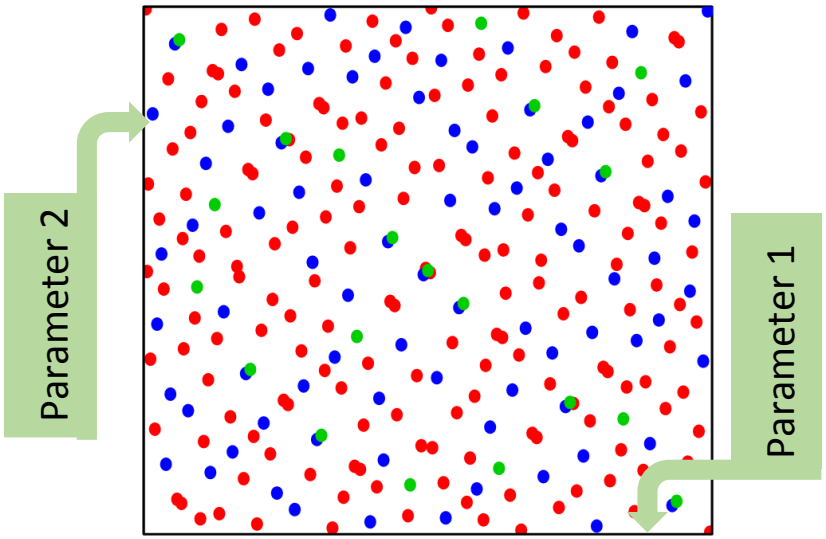
- Simple: Fit the CERES-Maize anthesis date parameters to the maize NAM lines and then QTL map the results



Lamsal et al., PLOS ONE doi: 10.1371/journal.pone.0195841

…that we could never have explained if we hadn't used …

Sobol sequence points



Massively parallel computing

Used = 32,400,070-member Sobol sequence

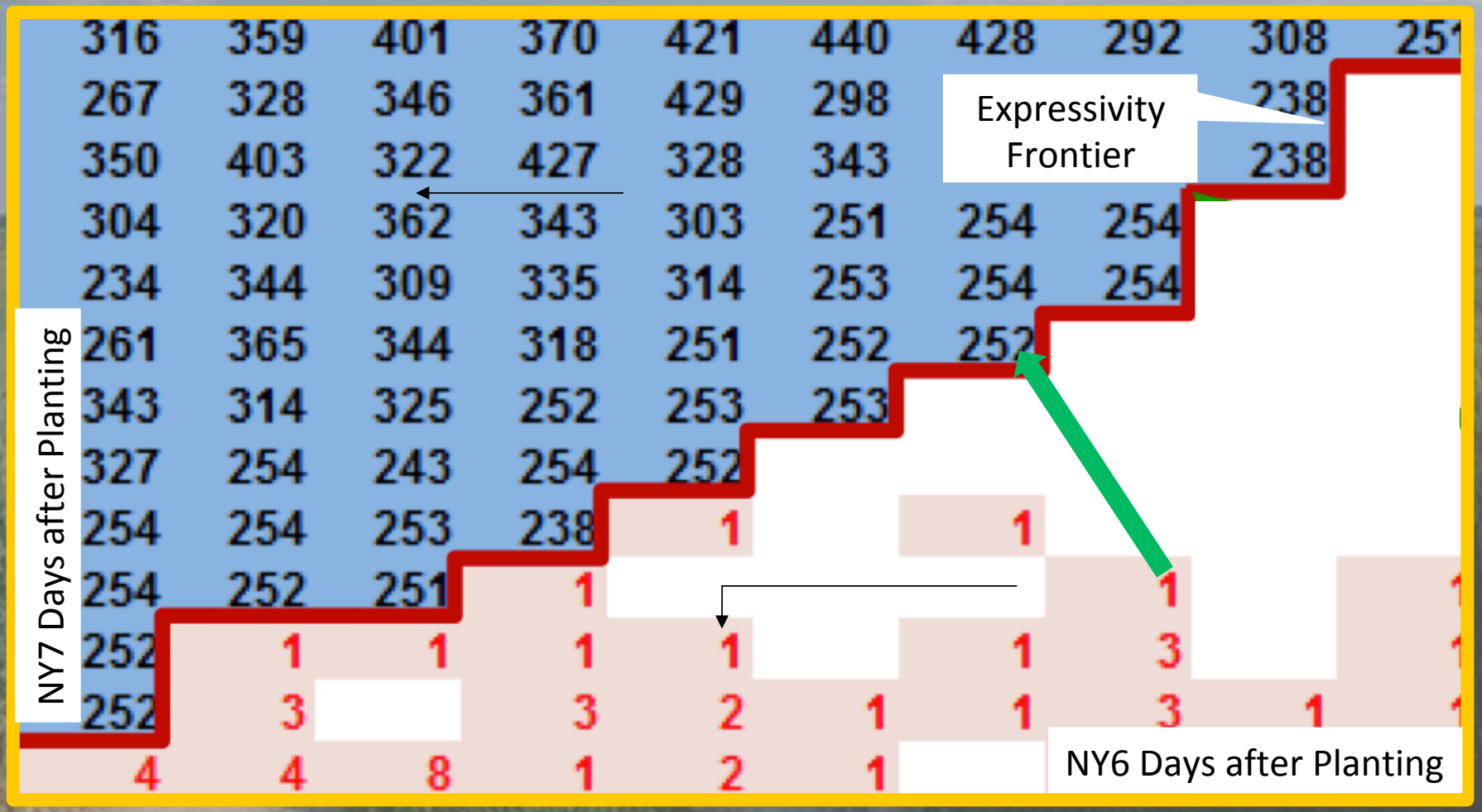
11 Site-years = 356,400,770 model runs

Ca. 67,500 CPU-Hrs

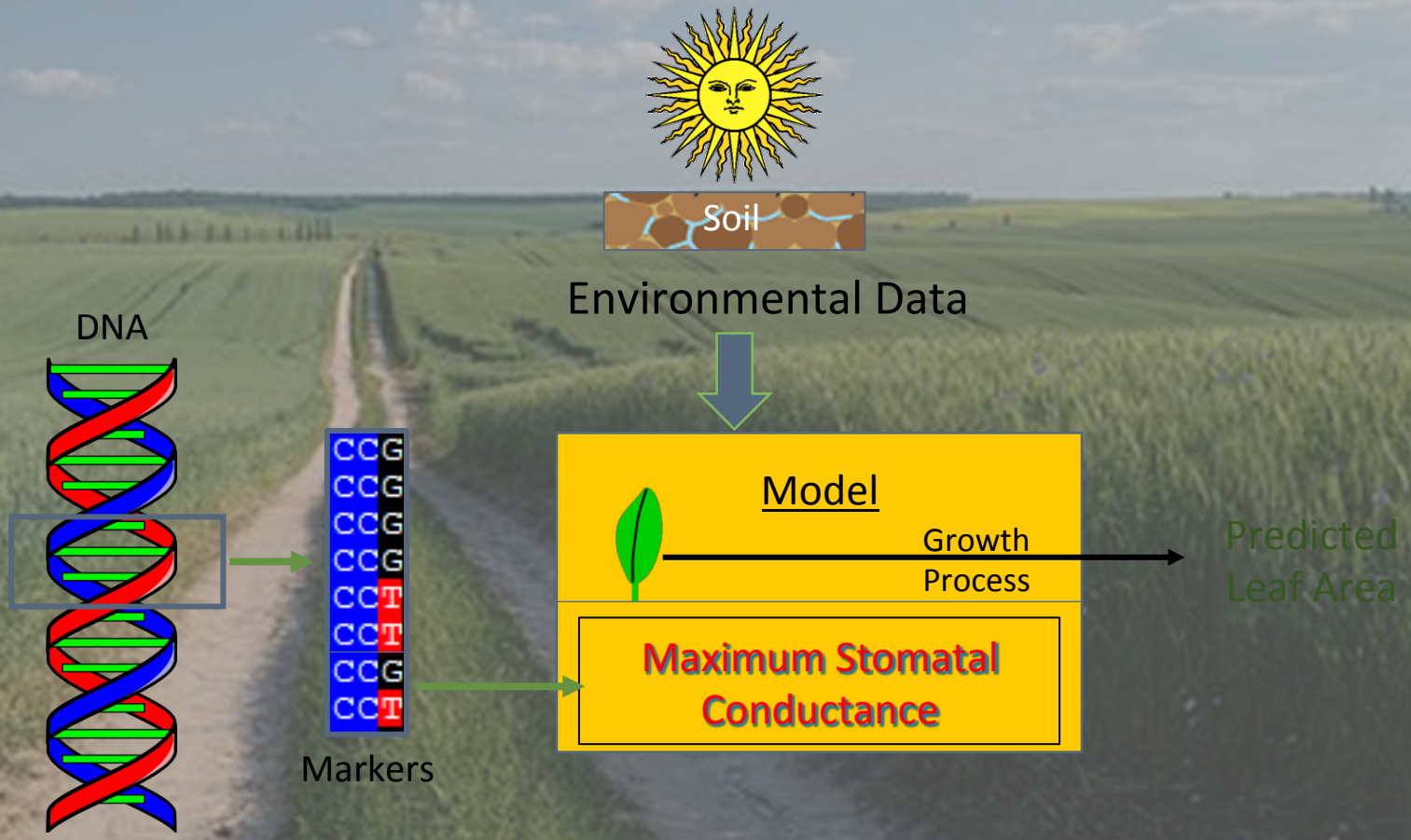
Then: Database search - Find each line's best values.

Ca. 1400 CPU-Hrs

But it still took 1…and that's not all…



“Genetic Specific Parameters” should only depend on genetics



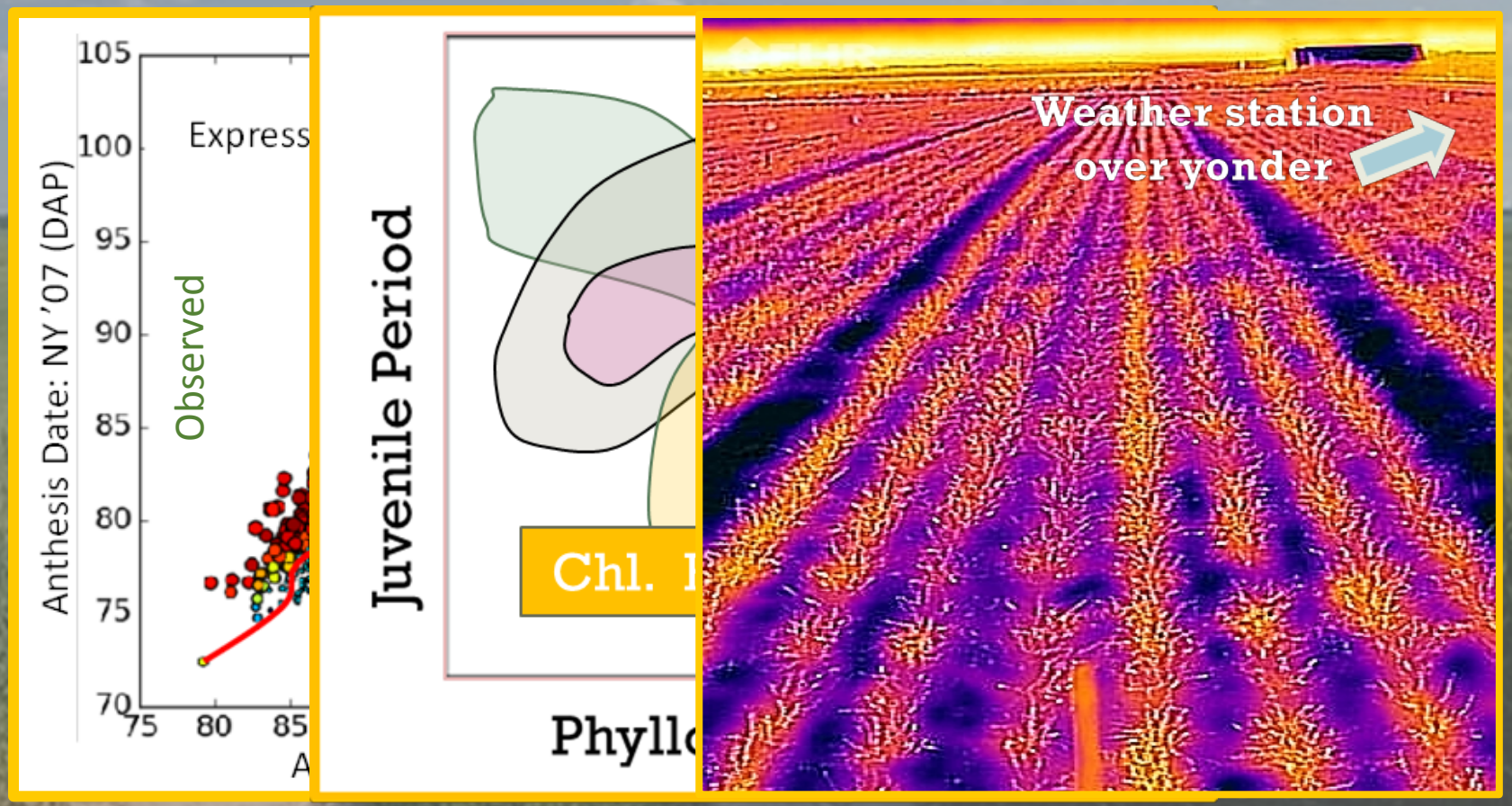
But they depended on the set of environments used in estimation

$$\rho_{l,es} = \mu_\rho + \alpha_l + \beta_{es} + \varepsilon_{l,es}$$

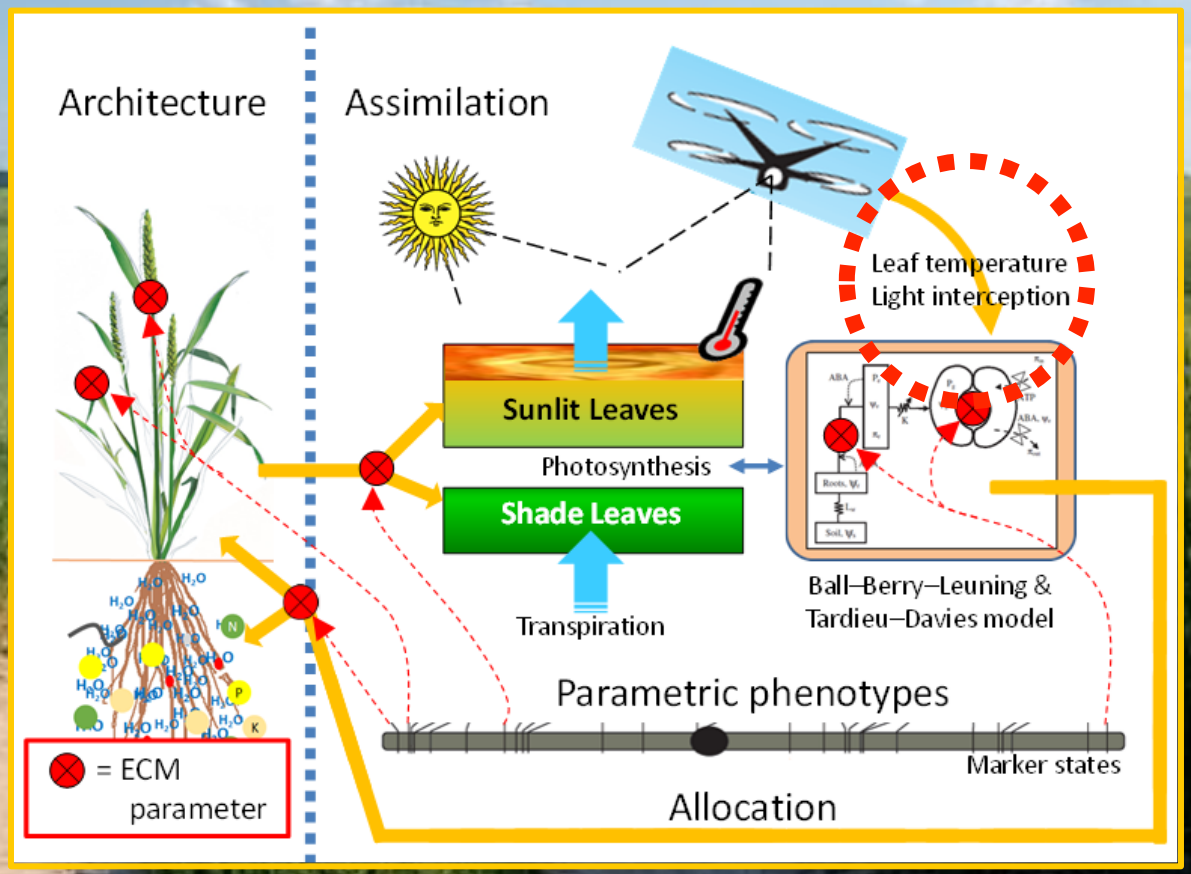
$$N = 539 \times \binom{11}{7} = 539 \times 330 = 177,870$$

$$\mathrm{H}_0 \colon \mathrm{Var}\left[\beta_{es}\right] = 0$$

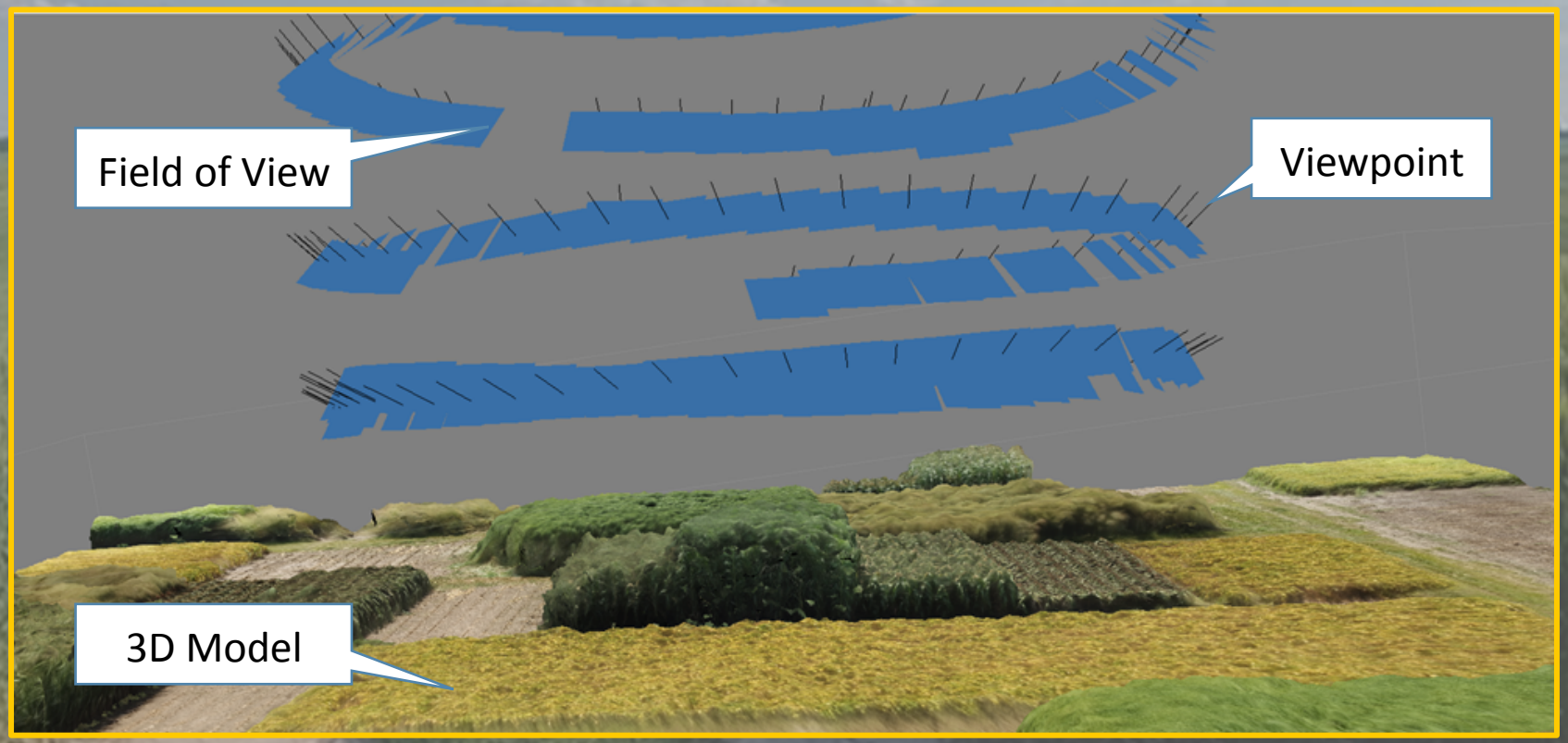
What should we do?



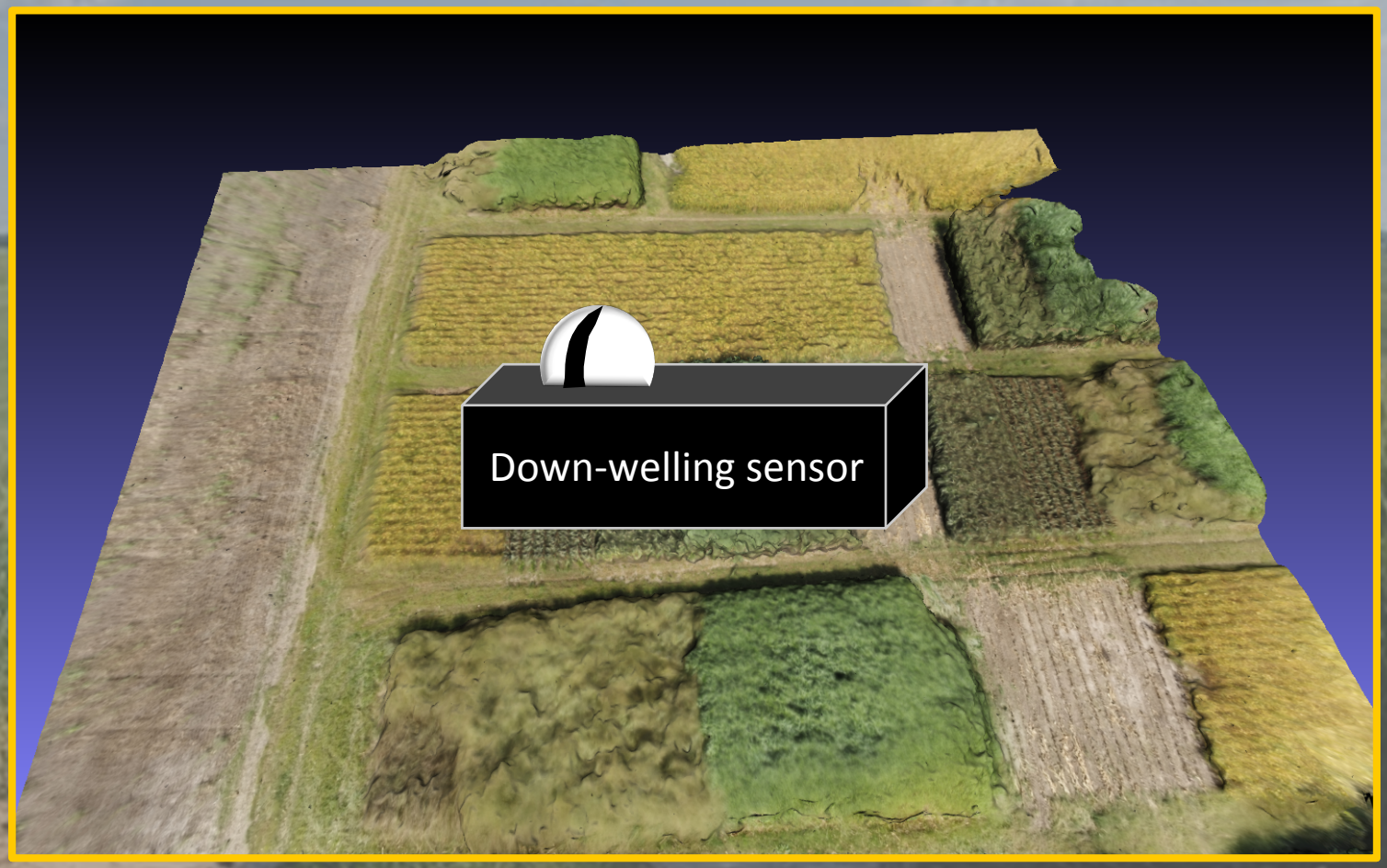
Rebalancing modeling & monitoring
Huh??? What's that??



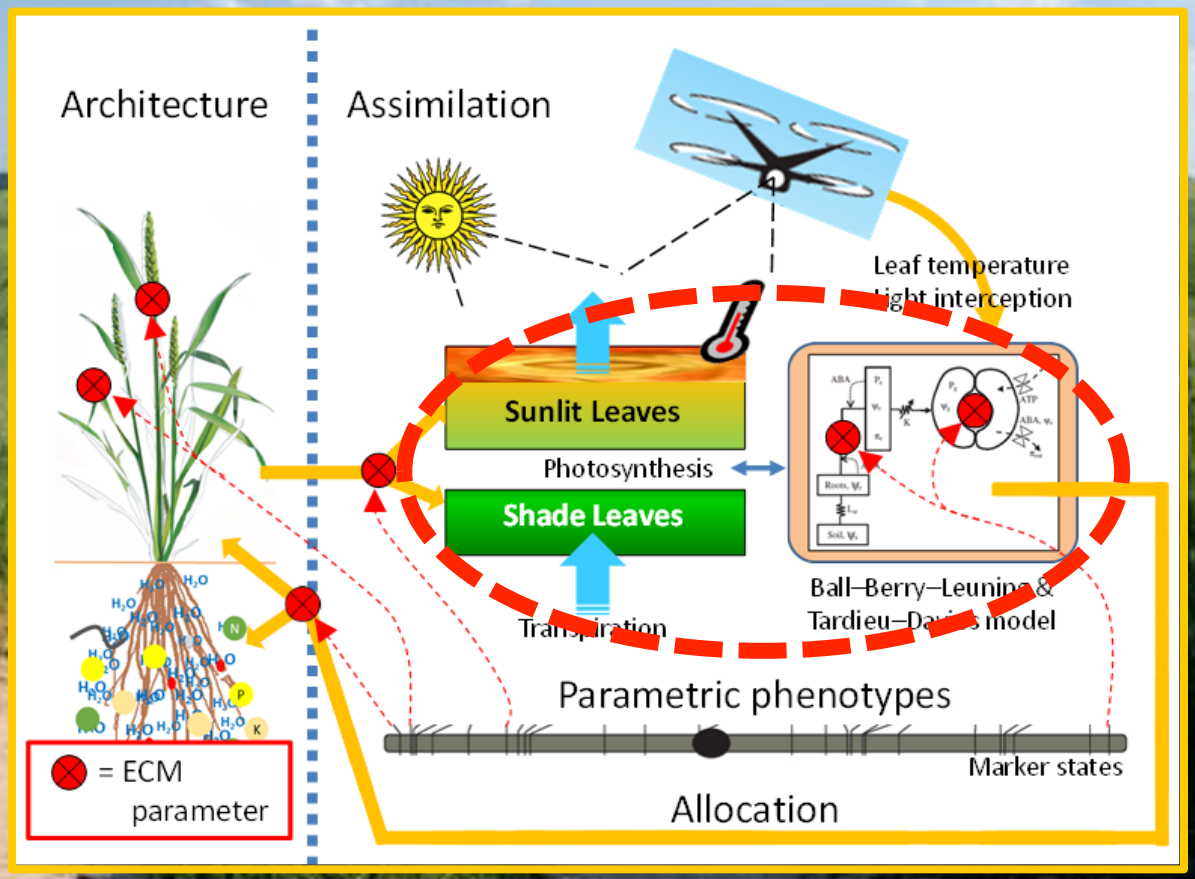
Canopy light interception by UAV



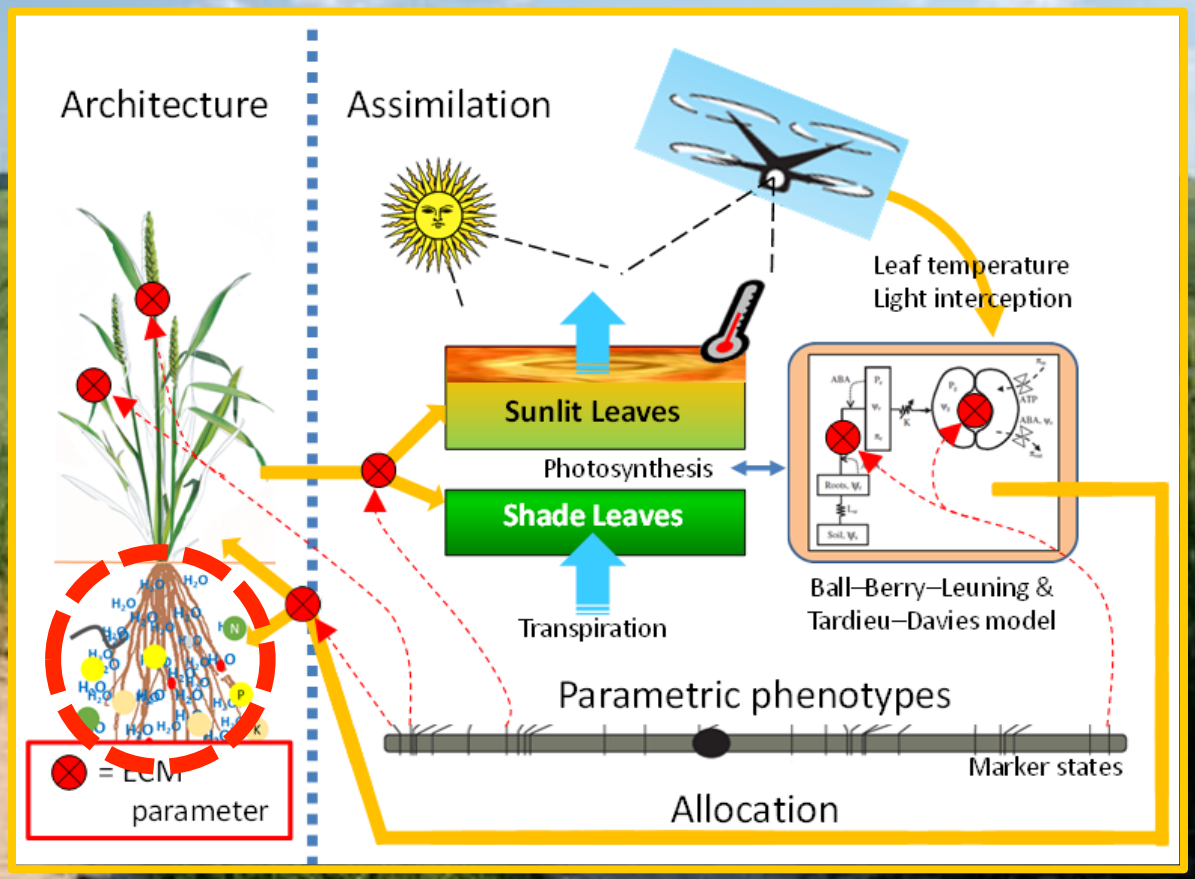
Bidirectional Reflectance Function



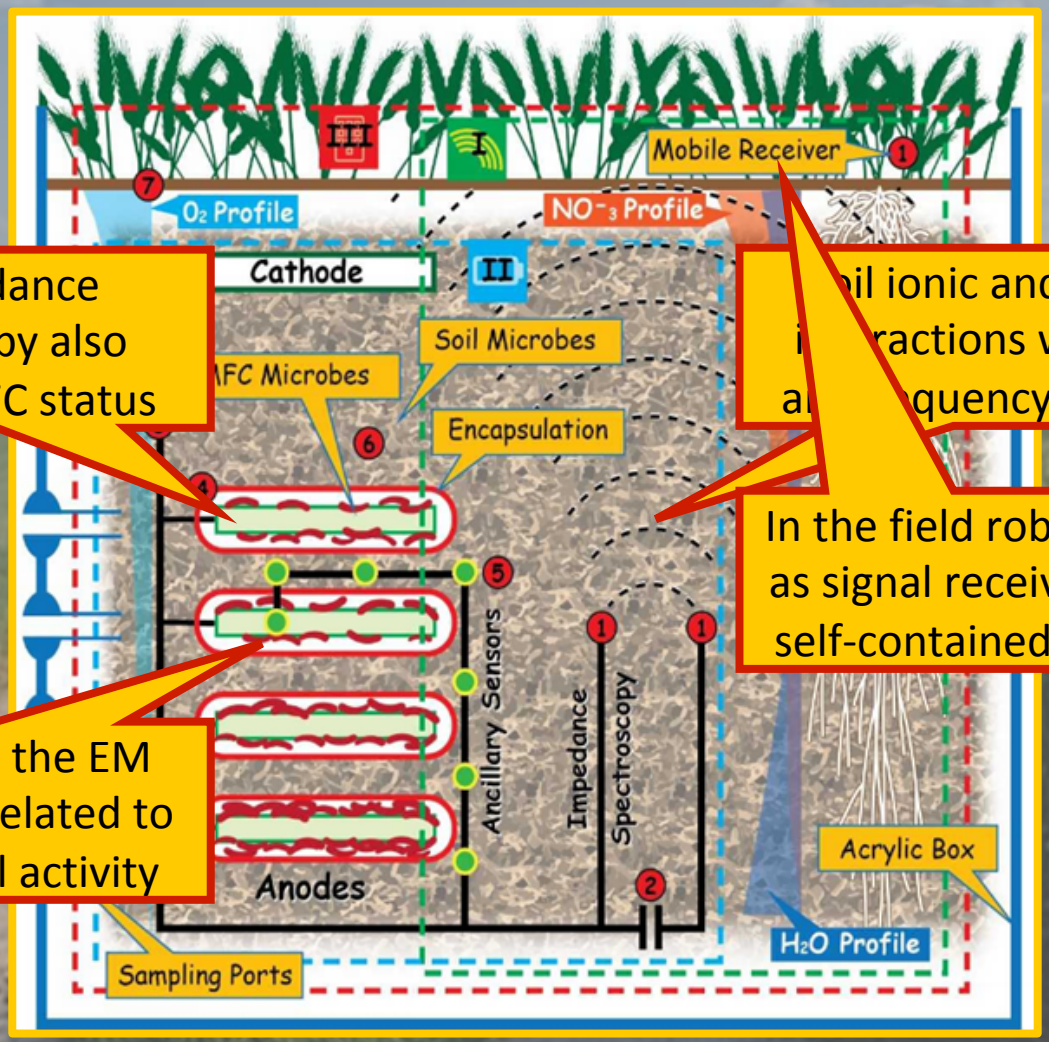
Water fluxes



Soil moisture, chemistry, & microbial activity



Soil Impedance spectroscopy and microbial fuel cells



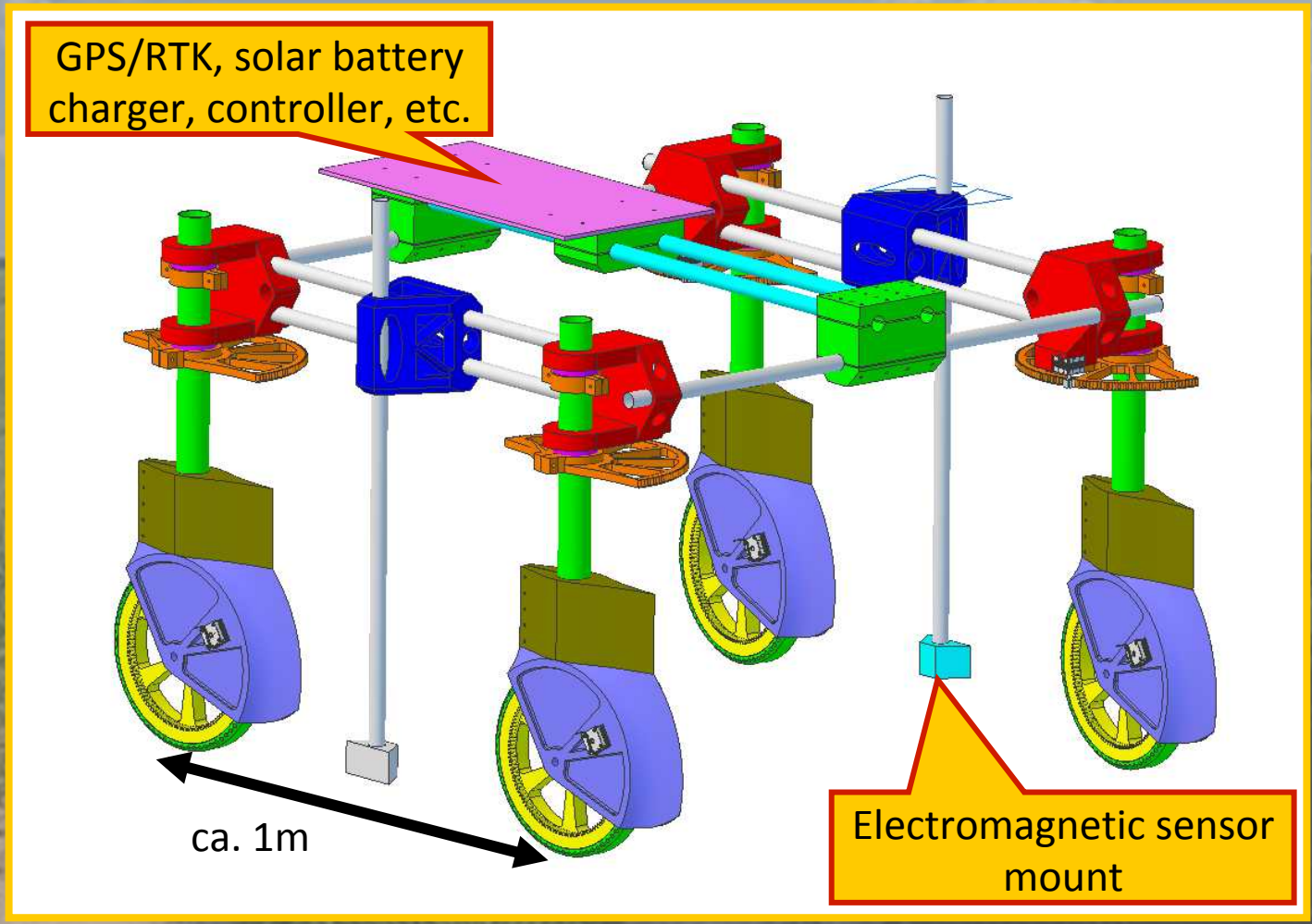
EM impedance spectroscopy also monitors MFC status

il ionic and water ractions with EM quency-specific

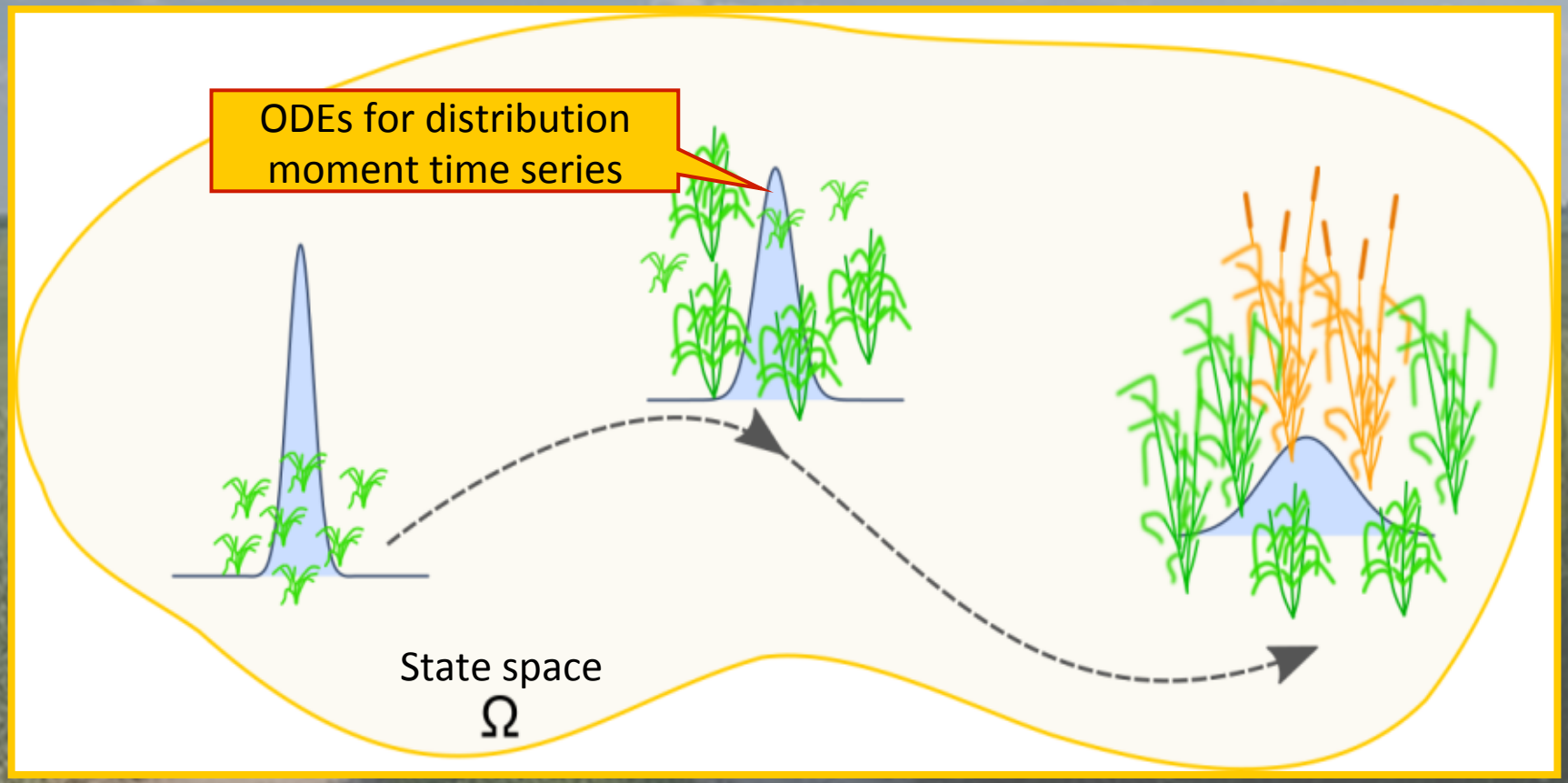
In the field robots serve as signal receivers &/or self-contained systems

MFCs power the EM unit at rates related to soil microbial activity

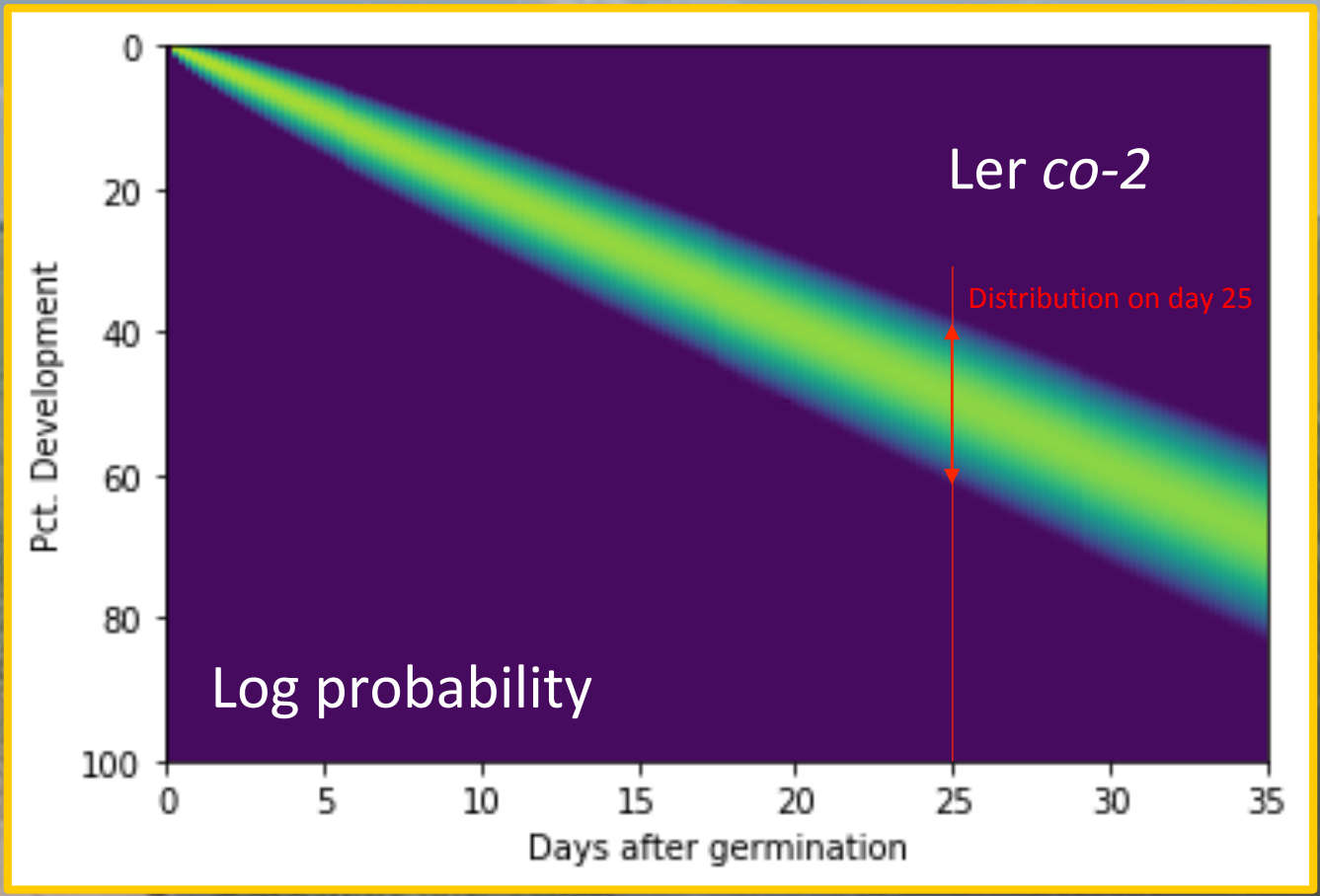
“Within canopy” mobile platform



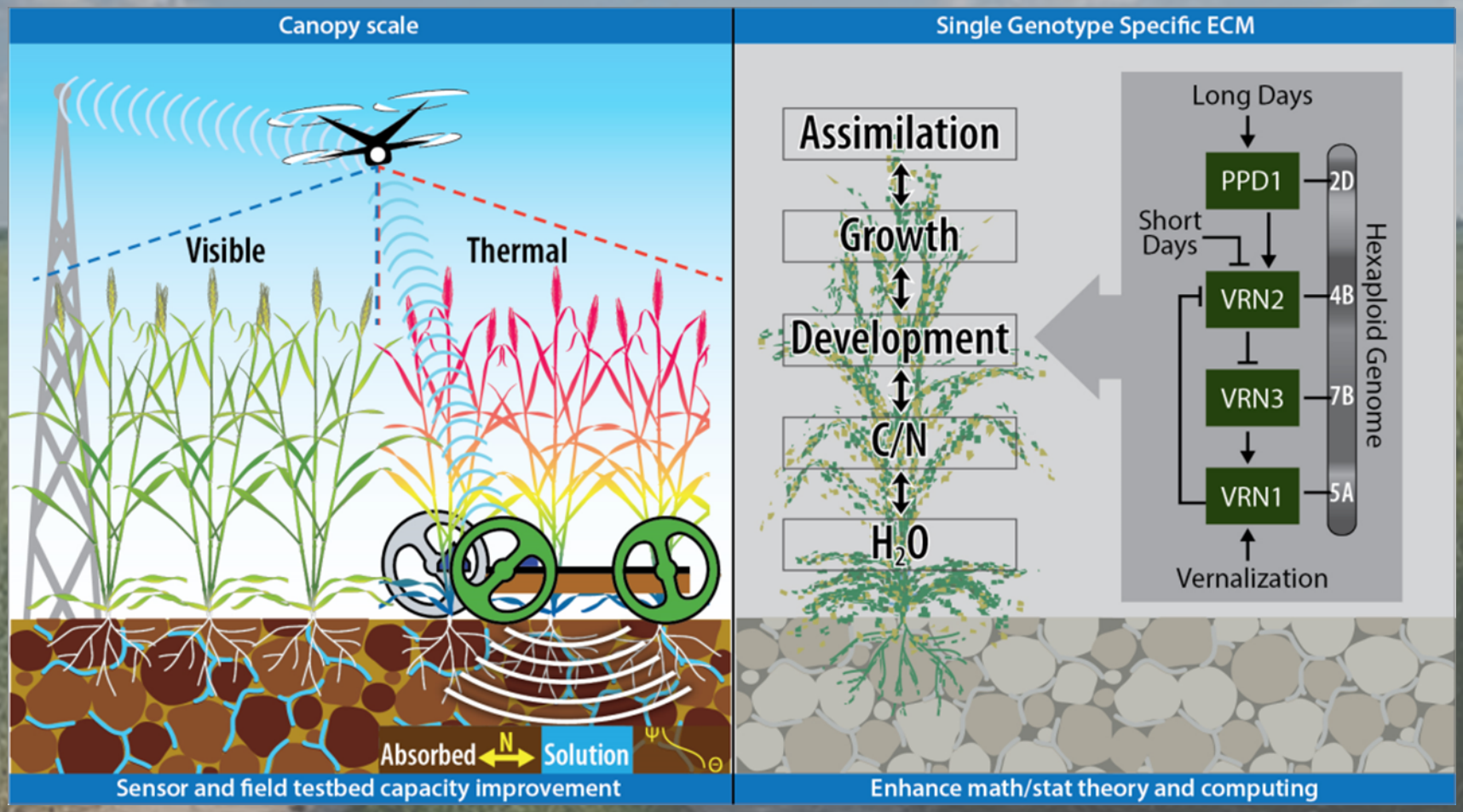
Modeling variation



Example from *A. thaliana*



The concept,….


Canopy scale
Visible
Thermal
Absorbed
N
Solution
Sensor and field testbed capacity improvement
Single Genotype Specific ECM
Assimilation
Growth
Development
C/N
H_2O
Long Days
PPD1
2D
Short Days
VRN2
4B
VRN3
7B
VRN1
5A
Hexaploid Genome
Vernalization
Enhance math/stat theory and computing

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