# Remotely Sensed Hybrid Phenology Matching Model to Estimate Crop Growing Stages


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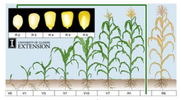
## ABSTRACT

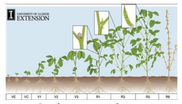

- Large-scale monitoring of crop phenological dynamics in a consistent and systematic manner is vitally crucial for optimizing the farm management activities and evaluating the agricultural resilience to extreme weather conditions and future climate change.
- However, our ability to retrieve crop growing stages with satellite time series is limited. The remotely sensed phenological transition dates may not be characteristic of crop physiological growing stages.
- The objective is to develop a hybrid phenology matching model to robustly retrieve a diverse spectrum of crop phenological stages using satellite time series.
- The hybrid phenology matching model leverages the complementary strengths of phenometric extraction methods and phenology matching models.
- The hybrid phenology matching model can characterize key phenological stages of crop cycles, ranging from farming practice-relevant stages to crop development stages.


## INTRODUCTION

- Remotely characterizing crop phenological progress throughout the growing season is an important but challenging task.
  - Farm management practices
  - Crop growth condition estimations
  - Crop yield predictions




Corn growth stages




Soybean growth stages

Description of phenological development stages for corn and soybean by NASS, USDA*.

| Corn | | Soybean | |
|---|---|---|---|
| Phenological stage | Description | Phenological stage | Description |
| Emerged | As soon as the plants are visible | Emerged | As soon as the plants are visible |
| Silking | The emergence of silk like strands from the end of ears | Blooming | A plant should be considered as blooming as soon as one bloom appears. |
| Dough | Normally half of the kernels are showing dent with some thick or dough-like substance in all kernels. | Setting pods | Pods are developing on the lower nodes with some blooming still occurring on the upper nodes. |
| Dent | Occurs when all kernels are fully dented and the ear is firm and solid. There is no milk present in most kernels. | Turning yellow | Leaves of soybean start to turn yellow |
| Mature | Plant is considered safe from frost. Corn is about ready to harvest with shucks opening and there is no green foliage present. | Dropping leaves | Leaves near the bottom of the plant are yellow and dropping, while leaves at the very top may still be green. Leaves are 30-50 percent yellow. |
| Harvest | Plant is cut, threshed, or otherwise gathered from the field. | Harvest | Plant is cut, threshed, or otherwise gathered from the field. |

*Adapted from crop progress terms and definitions of NASS, USDA (https://www.nass.usda.gov/Publications/National_Crop_Progress/terms_definitions.php)

**Three challenges**

1) Remotely sensed phenological characteristics may not be linked to crop physiological development stages.
2) Most remotely sensed crop phenological studies are constrained to limited crop physiological growing stages.
3) Remotely sensed phenological characteristics have not been appropriately validated with field-based crop phenological observations.


## OBJECTIVE

**Develop a hybrid phenology matching model to retrieve a wide range of crop phenological stages.**

1) **Hybrid phenology matching model:** integrate the designs of phenometric extraction and phenology matching models
2) **Phenological reference:** design various phenological reference scenarios with publicly available phenological information

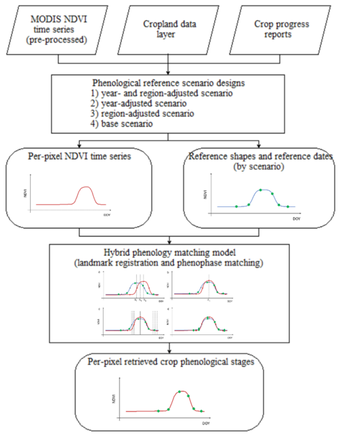
## STUDY SITE

- The study site is Illinois, US. Two major crops in Illinois are corn and soybean. Their sowing times vary across years and locations, depending on temperature conditions, soil moisture, and farm management decisions.
- Based on geography, climate and cropping practices, Illinois is partitioned into nine agricultural statistics districts (ASDs).

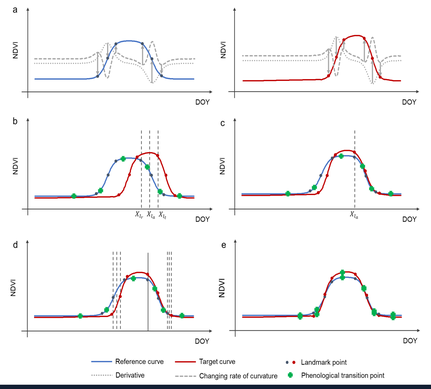

## HYBRID PHENOLOGY MATCHING MODEL

Hybrid phenology matching model expands crop phenological monitoring to potentially any phenological stages.

- Integrate phenometric extraction and phenology matching models
- Retrieve both farming practice and crop development stages (e.g. corn planted, emerged, silking, dough, dent, mature, harvested stages)




The hybrid phenology matching model for estimating phenological transition dates of target NDVI time series curves:




## PHENOLOGICAL REFERENCE DESIGN

Phenological matching: Calibration of phenological reference shapes and dates.

We design four phenological reference scenarios using USDA Crop Progress Reports (CPRs):

Scenario 1: year- and region-adjusted scenario

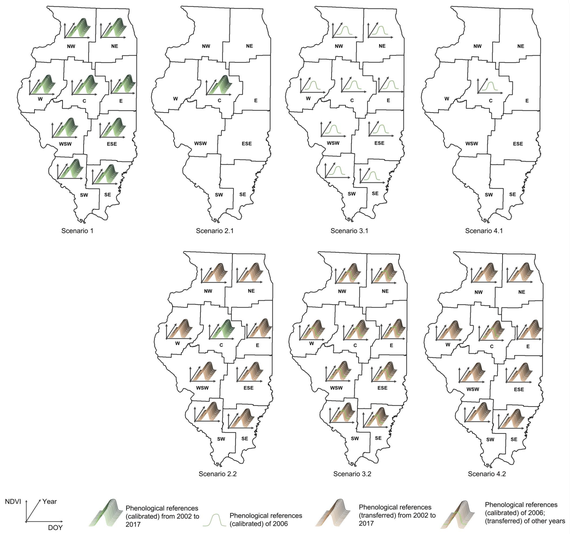
Scenario 2: year-adjusted scenario

Scenario 3: region-adjusted scenario

Scenario 4: base scenario

| Scenario | Reference Shape | Reference Date | NASS CPR | Calibration Level |
|---|---|---|---|---|
| Scenario 1 | Year- and ASD-adjusted | Year- and ASD-calibrated | CPR data for all years and ASDs | Accommodate both inter-annual and regional crop phenological variations in reference designs |
| Scenario 2.1 | Year-adjusted, central ASD | For each year, central ASD calibrated | CPR data for all years of central ASD | Accommodate inter-annual crop phenological variations in reference designs |
| Scenario 2.2 | Year- and ASD-adjusted | For each year, central ASD calibrated, other ASDs transferred | | |
| Scenario 3.1 | Year 2006, ASD-adjusted | For each ASD, year 2006 calibrated | CPR data for all ASDs in 2006 | Accommodate regional crop phenological variations in reference designs |
| Scenario 3.2 | Year- and ASD-adjusted | For each ASD, year 2006 calibrated, other years transferred | | |
| Scenario 4.1 | Year 2006, Central ASD | Central ASD in 2006 calibrated | CPR data for central ASD in 2006 | Not accommodate either inter-annual or regional crop phenological variations in reference designs |
| Scenario 4.2 | Year- and ASD-adjusted | Central ASD in 2006 calibrated, other year-ASD combinations transferred | | |

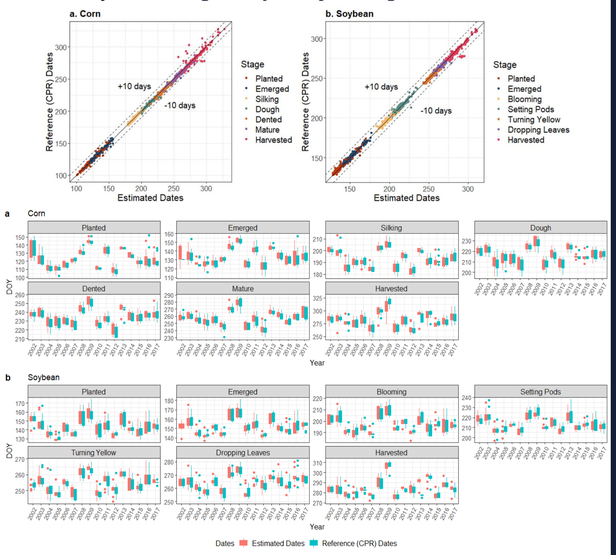
Design of four phenological reference scenarios with varying levels of phenological calibrations.



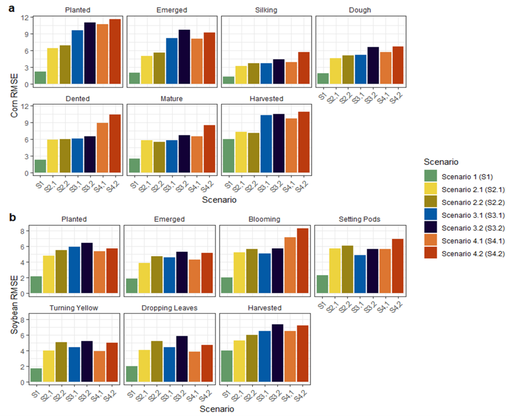

*The reference shapes in green denote that the corresponding reference dates are calibrated for the associated year-ASD combinations. The reference shapes in yellow denote that the corresponding reference dates are not calibrated, but transferred for the associated year-ASD combinations.*

## RESULTS

1) Crop phenological stages are estimated with high accuracy under year- and region-adjusted phenological reference




2) The calibration level of phenological reference affects the phenological retrieval accuracy




## CONCLUSIONS

- The hybrid phenology matching model can retrieve the crop phenological progress from planted to harvested stages.
- The phenological reference design affects the crop phenological retrieval accuracy.
- The devised model paves the way for formulating standard large-scale crop phenological monitoring protocols via remote sensing.


## ACKNOWLEDGMENT

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