Early Estimate of Crop Emergence Date using Sentinel-2 over the Free State Province, South Africa

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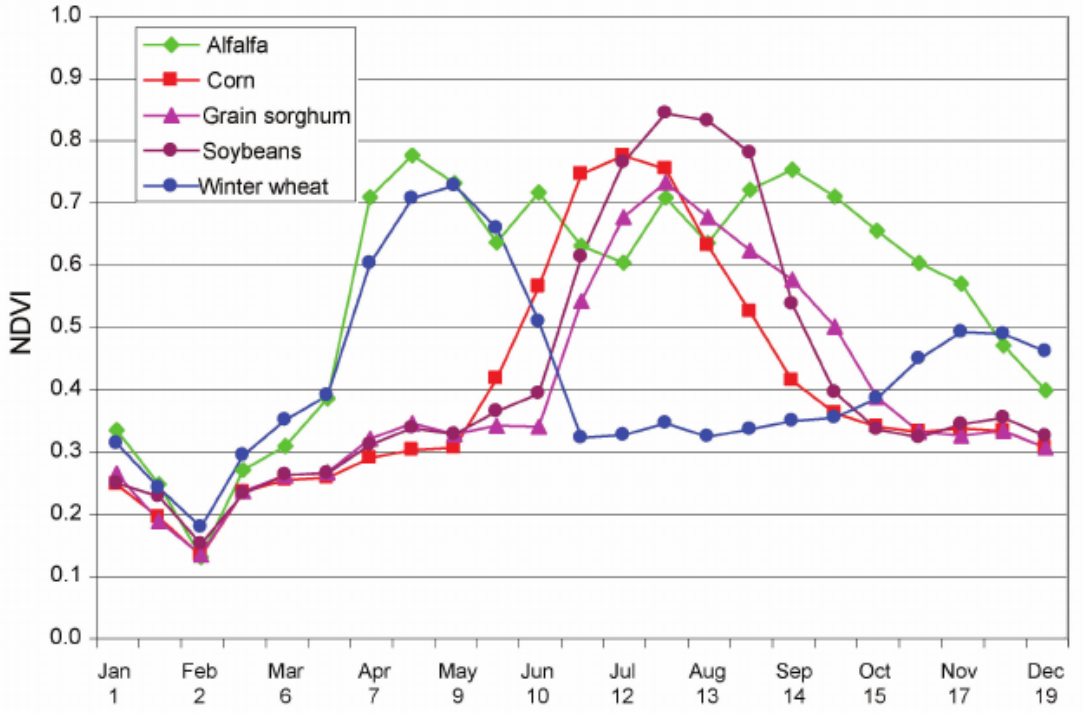
Challenge

DETECTING A CROP DEVELOPMENT STAGE IN SEASON ?

sentinel-2

→ AGRICULTURE



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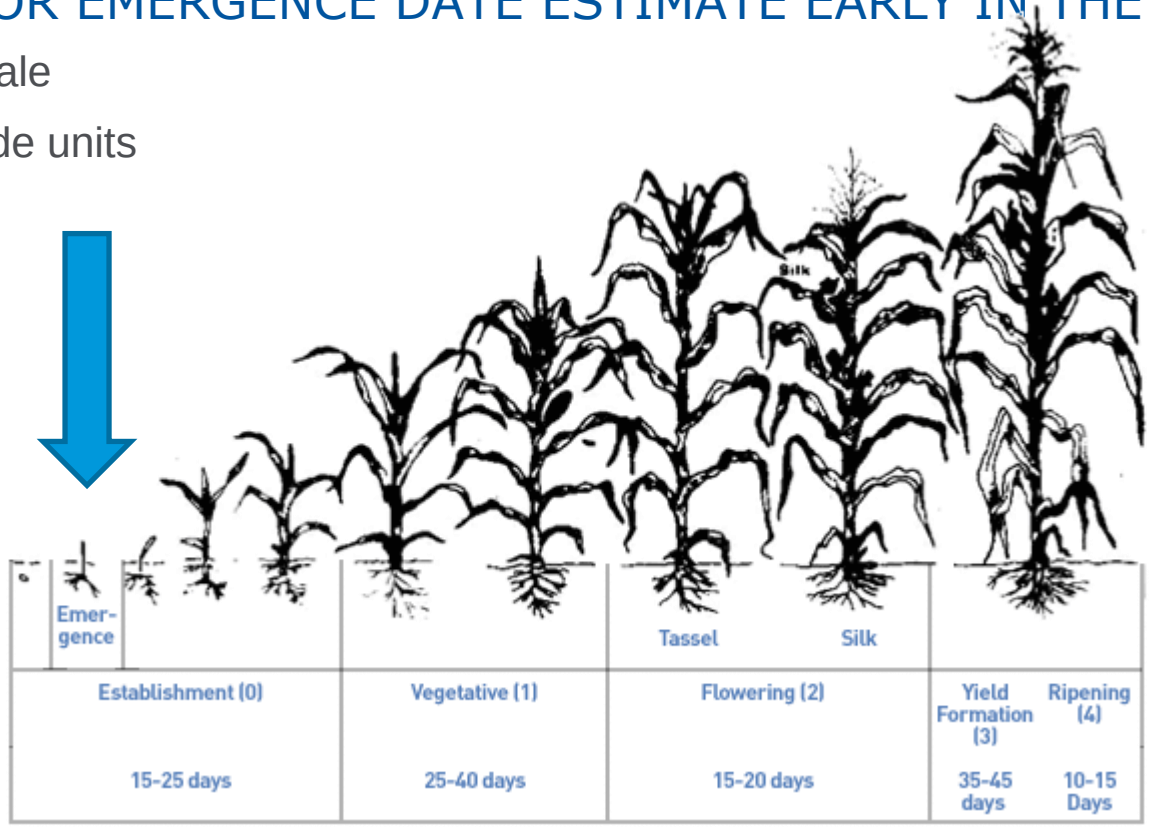
Current information

FIELD SURVEY FOR EMERGENCE DATE ESTIMATE EARLY IN THE SEASON

BBCH scale

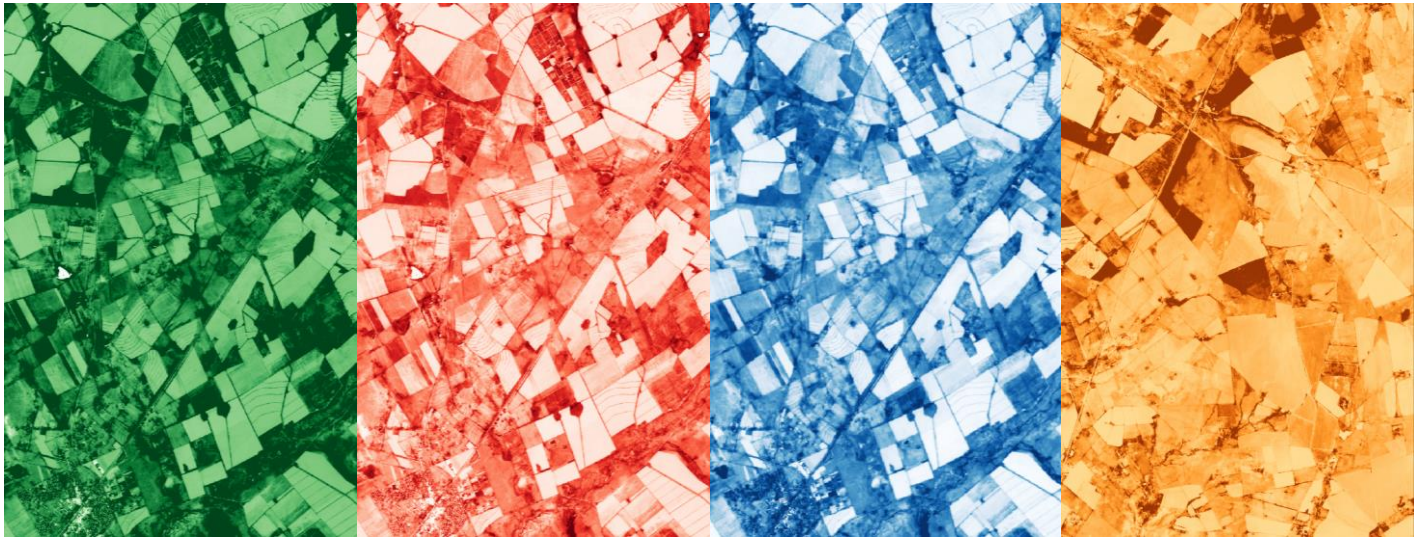
0-100 code units



Sen2-Agri time series and derived indices

Building Sentinel-2 index time-series

NDVI | MSAVI2 | Hue index | Leaf Area Index



sentinel-2

+ AGRICULTURE

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OBJECTIVES

Development of a generic method to estimate emergence date as early as possible in near real time based on Sentinel-2 time series (Sen2-Agri output)

⇒ Insurance companies, ag. services
⇒ Emergence date critical for yield forecasting

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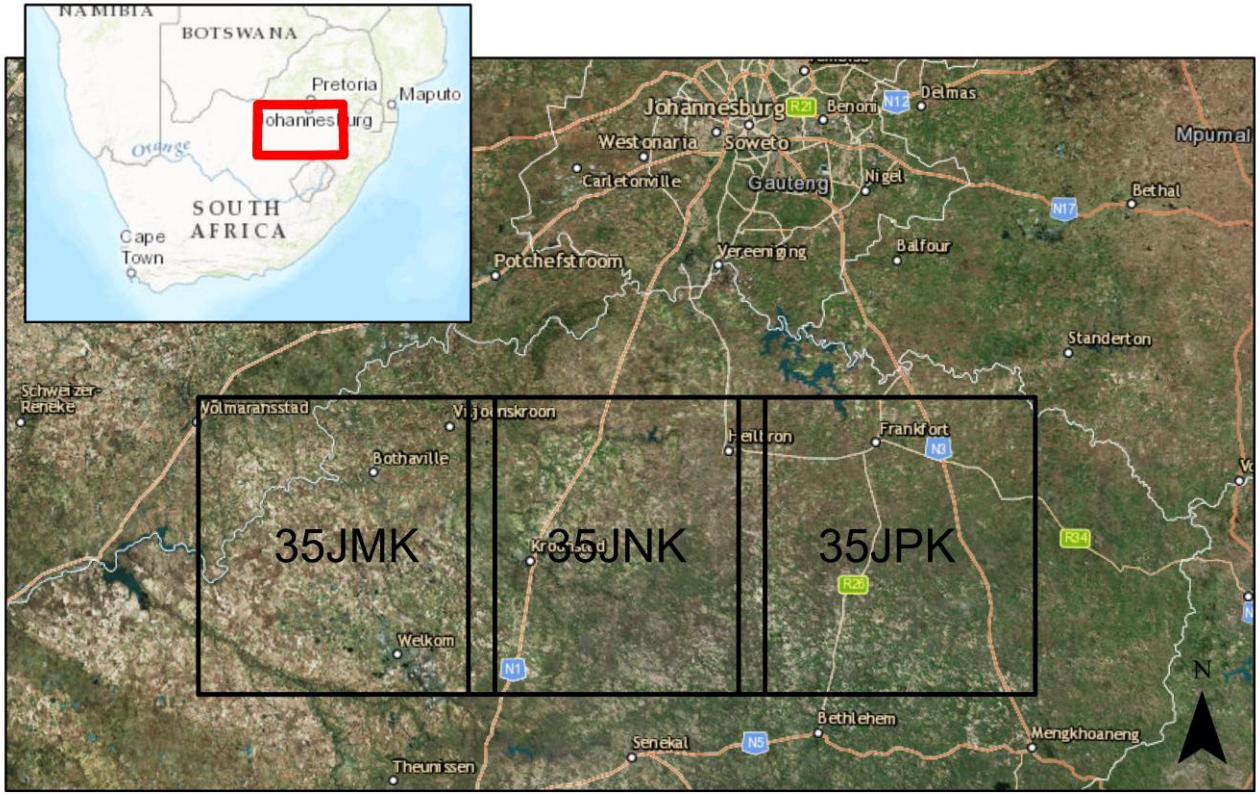
STUDY AREA - Free State (South-Africa)



30 000 km²

3 Sentinel-2 tiles
300 km x 100 km

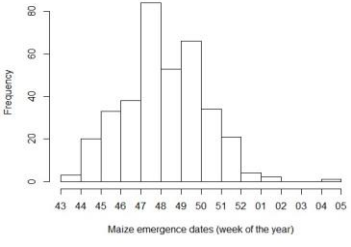
In situ observation and meteorological data

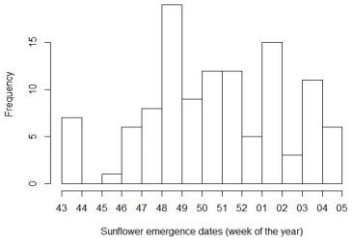
Emergence reports (from field survey)

- emergence date
- growth stage
- GPS coordinates
- crop density and row width

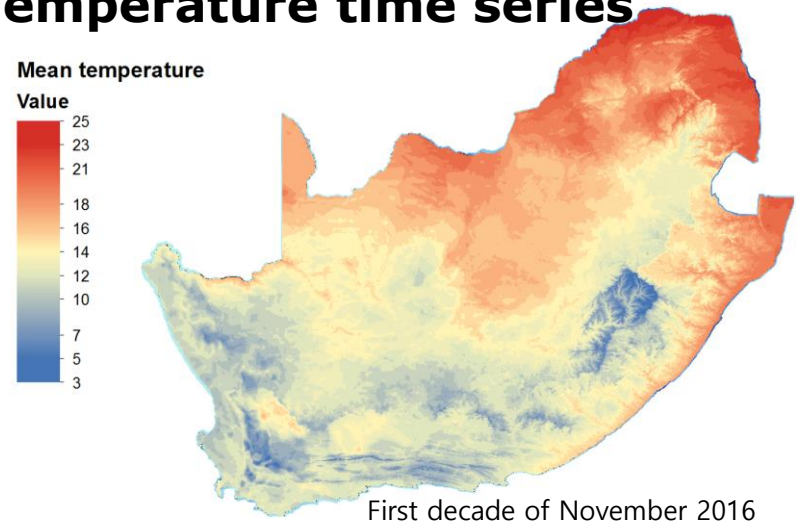
for 2 commercial crops :

359 fields 114 fields





Temperature time series



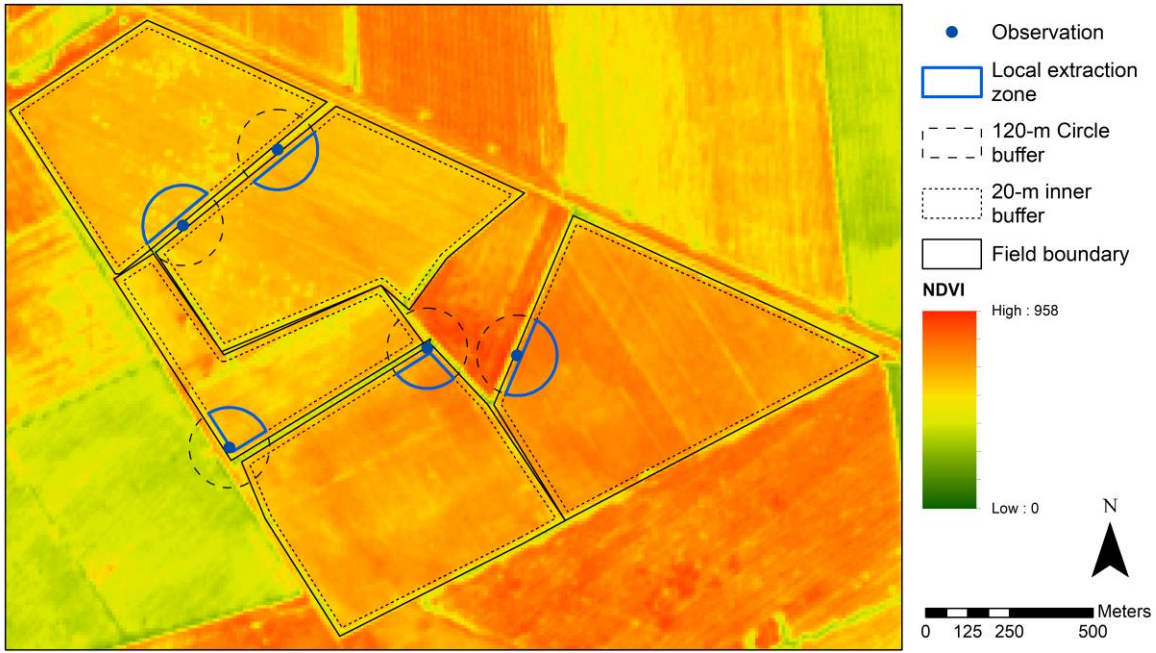
First decade of November 2016

Linking in situ observation and EO imagery

Field boundaries (from PICES)

Extracted samples of 1.8 ha on average

EO extraction at location of field observation



⇒ Critical because of very large field sizes and high field heterogeneity

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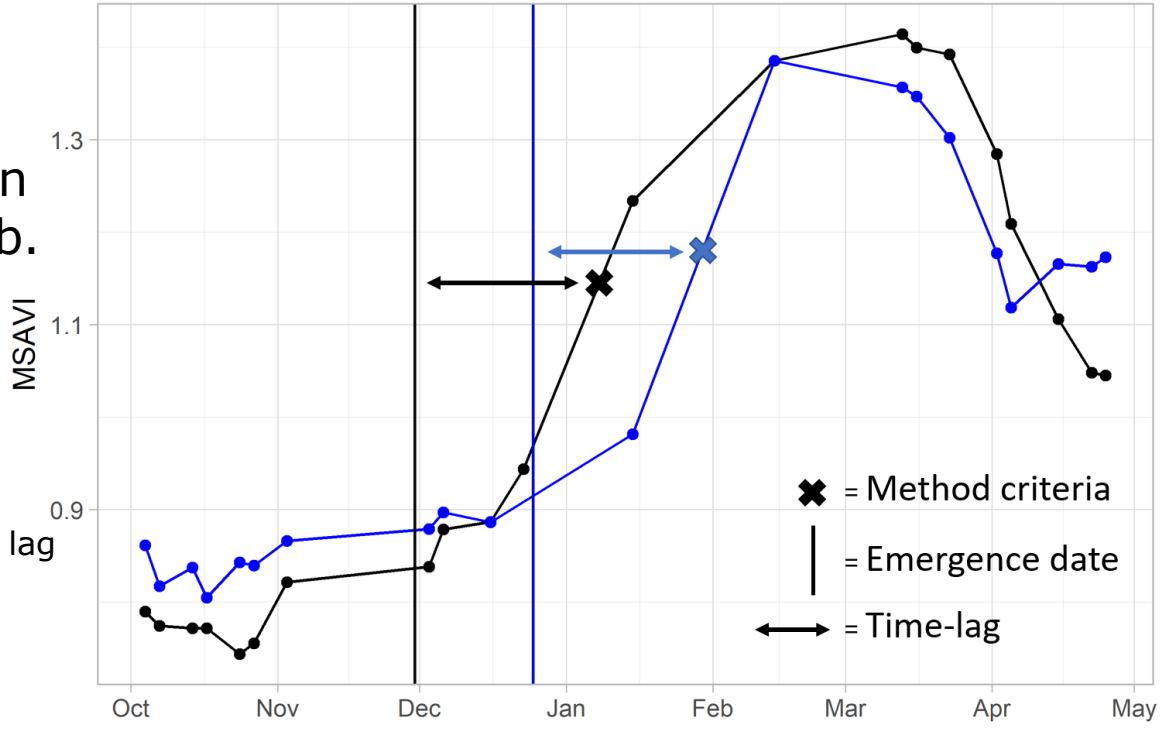
PRINCIPLE OF EMERGENCE DATE DETECTION

1. Method criteria ✖
2. Criteria without calibration
2′. Criteria with time lag calib. using in situ obs. ⟷
3. Emergence date estimate

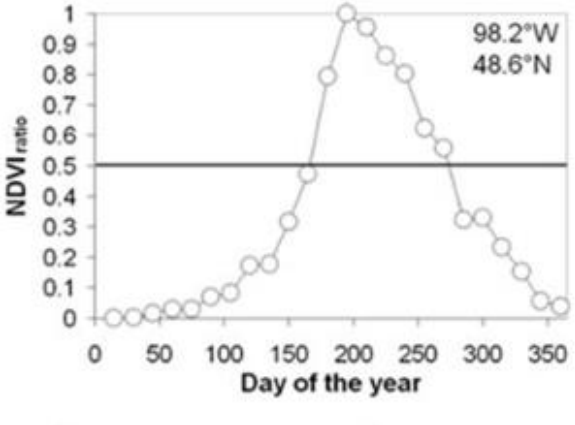
Em. date (day) = criteria date – time lag

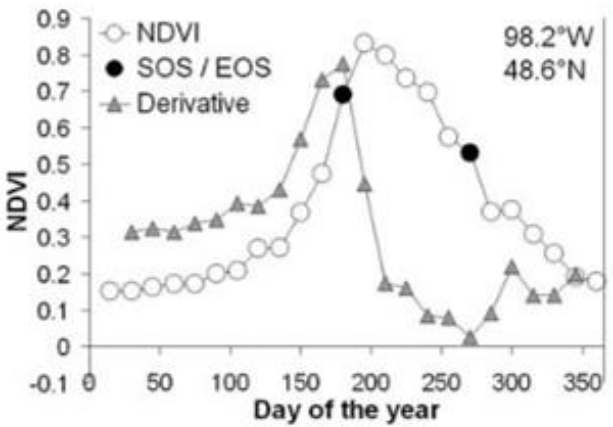


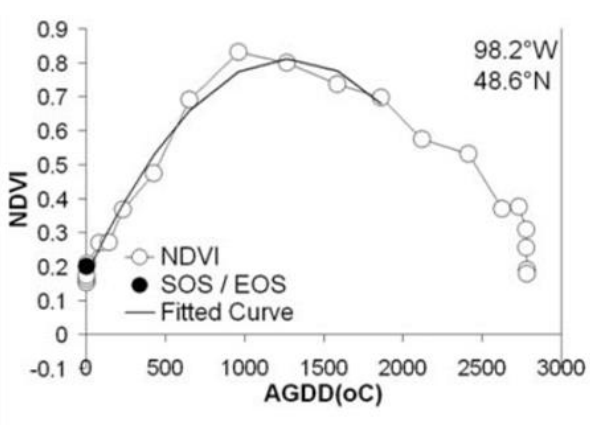
Performance assessment using 6 metrics
(incl. Standard Deviation and Mediane Absolute Deviation)

DETECTION METHOD – elements to benchmark

- *4 variables :* NDVI MSAVI2 Hue index Leaf Area Index (LAI)
- *2 interpolation algo. :* Linear interpolation Logistic interpolation
- *6 criteria:* Abs./rel.threshol Derivative methods Model fitting







2010

- *2 Time scales :* Calendar time (Julian day Thermal time (growing degree days)

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RESULTS – Criteria without calibration

Maize mergence date estimation

215 samples for calibration / 108 samples for validation

No really interesting results

		MSAVI		NDVI		Hue index		LAI	
		calib	valid	calib	valid	calib	valid	calib	valid
Inflection point	SD	19.7	19.8	17.6	14.1	12.5	37.9	Not applicable	
	MAD	7.4	9.6	7.4	8.9	8.9	7.4		
	Time-lag	30.6	31.1	35.1	33.3	26.4	27.5		
Base logistic	SD	14.1	16.7	12.1	15.1	13.5	12.2	Not applicable	
	MAD	13.3	14.1	10.4	11.1	10.4	9.6		
	Time-lag	1.3	-2.1	8.0	5.5	5.9	5.8		
Maximum value	SD	17.6	17.5	17.7	17.4	18.5	17.9	34	31.4
	MAD	19.3	20	19.3	20.8	19.3	20	31.1	23.7
	Time-lag	96.4	94.6	96.3	94.6	97.9	95.8	79.4	78.6

SD : Standard Deviation
MAD : Mediane Absolute Deviation

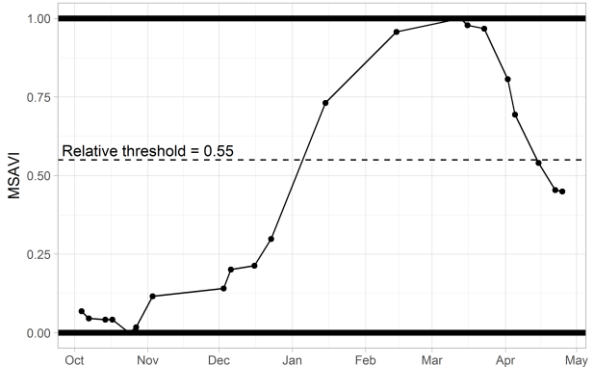
RESULTS – Criteria with calibration

Maize mergence date estimation 215 samples for calib. / 108 samples for validation

		MSAVI		NDVI		Hue index		LAI	
		calib	valid	calib	valid	calib	valid	calib	valid
Absolute threshold (linear interpolation)	SD	10.8	12.9	11.7	12.4	10.7	12.4	18.3	14.9
	MAD	8.9	10.4	8.9	11.9	10.4	10.4	13.3	14.8
	Time-lag	17.0		28.5		22.7		-32.7	
	min/bias	SD	-0.9	MAD	0.9	SD	-2.3	SD	-4.5
Relative threshold (linear interpolation)	SD	9.8	11.6	10.2	11.6	11.1	12	21.2	18.9
	MAD	7.4	8.9	7.4	8.9	10.4	11.1	22.2	23.7
	Time-lag	28.3		30.4		21.9		-13.1	
	min/bias	SD	-1.2	MAD	-0.2	SD	-1.5	SD	3.2
Absolute threshold (log. interpolation)	SD	10.2	10.5	10.7	11.5	9.3	10.3	Not applicable	
	MAD	11.9	8.2	7.4	10.4	9.6	7.4		
	Time-lag	25.3		22.6		24.1			
	min/bias	SD	-1.5	MAD	-1.2	SD	-1.3		
Relative threshold (log. interpolation)	SD	9.4	9.6	9.0	11.8	9.3	12.1	Not applicable	
	MAD	7.4	8.2	7.4	8.2	8.2	11.1		
	Time-lag	24.4		26.5		22.6			
	min/bias	SD	-0.6	SD	-1.6	MAD	-1.4		
Highest slope	SD	13.6	14.6	17.6	17.4	13.6	13.9	11.8	12.7
	MAD	8.9	11.1	10.4	10.4	10.4	10.4	11.8	13.3
	Time-lag	29.4	29.0	33.0	32.8	24.9	24.1	38.9	36.6

Most accurate results using MSAVI and NDVI

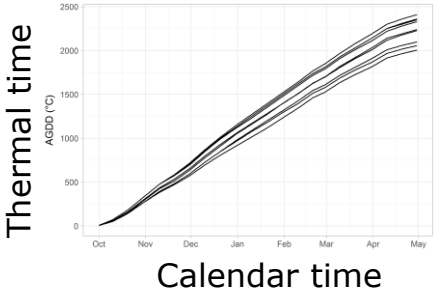
Relative threshold criteria

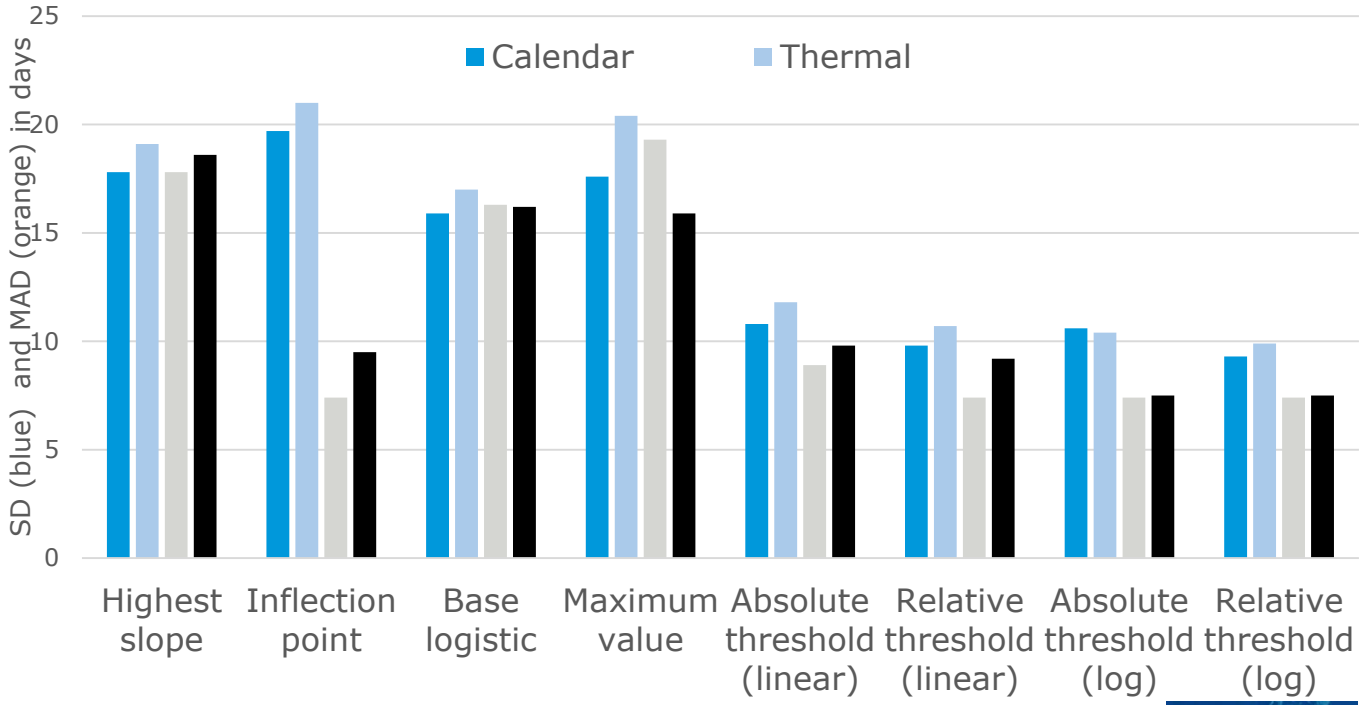


SD : Standard Deviation
MAD : Mediane Absolute Deviation

Little difference between calendar and thermal time

Differences for threshold, derivative method and model-fitting method





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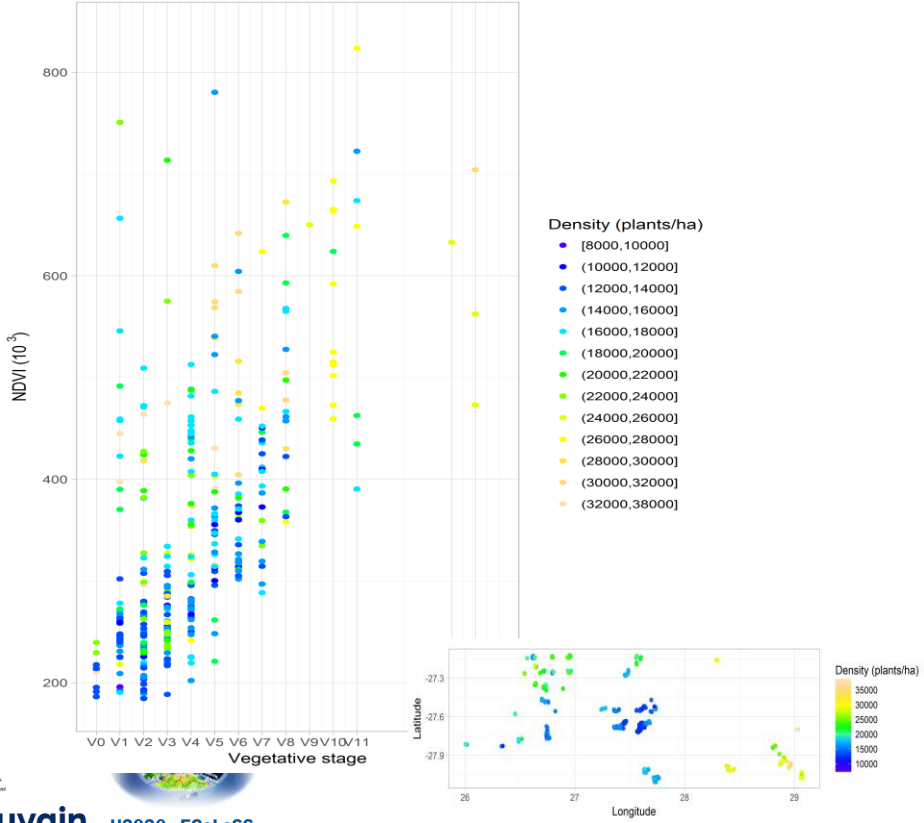
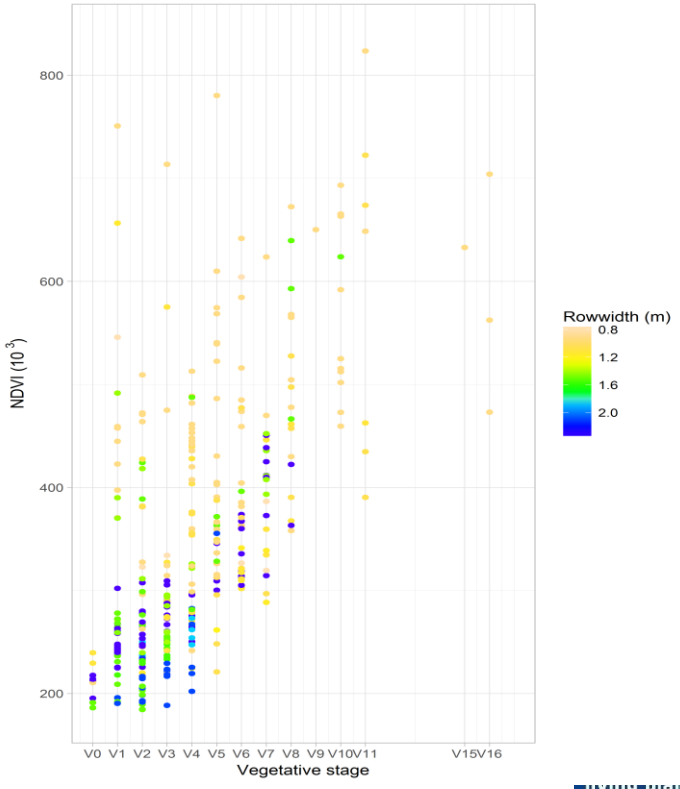
Strong influence of plant density and row width on NDVI but no impact on the best results (MSAVI rel. threshold)

Plant density



Crop row width



RESULTS – similar results for 2 different years

Similar results for maize for 2016-2017 and 2015-2016

but annual calibration required

(still using only Sentinel-2a for both years)

		MSAVI	
		2016-2017	2015-2016
Highest slope	SD	17.8	14.6
	MAD	17.8	7.4
	Time-lag	45.3	37.7
Inflection point	SD	19.7	12.1
	MAD	7.4	7.4
	Time-lag	30.6	40.2
Base logistic	SD	15.9	11.2
	MAD	16.3	5.9
	Time-lag	-6.5	22.0
Maximum value	SD	17.6	21.3
	MAD	19.3	22.2
	Time-lag	96.4	85.3
Absolute threshold (linear interpolation)	SD	10.8	13.0
	MAD	8.9	7.4
	Time-lag	17.0	27.7
Relative threshold (linear interpolation)	SD	9.8	12.8
	MAD	7.4	5.9
	Time-lag	28.3	33.2
Absolute threshold (logistic interpolation)	SD	10.6	10.0
	MAD	7.4	19.3
	Time-lag	18.9	27.5
Relative threshold (logistic interpolation)	SD	9.3	10.9
	MAD	7.4	5.9
	Time-lag	21.0	29.0

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RESULTS –

Similar results for sunflower

(Relative threshold using MSAVI but here linearly or log. interpolated)

Sunflower reports :
80 samples for calibration
34 samples for validation

		MSAVI		NDVI		Hue index		LAI	
		calib	valid	calib	valid	calib	valid	calib	valid
Inflection point	SD	19.4	17.9	15.1	16.4	22.6	10.9	Not applicable	
	MAD	11.9	11.9	10.4	11.9	13.3	7.4		
	Time-lag	19.8	21.4	25.1	26.0	16.4	14.8		
Base logistic	SD	20.7	16.0	17.6	11.6	26.5	19.1	Not applicable	
	MAD	17.8	13.3	11.9	14.8	14.8	5.2		
	Time-lag	-12.2	-6.0	-2.3	-2.9	-10.2	-4.5		
Maximum value	SD	15.9	18.6	15.8	18.3	17.8	21.5	31.7	35.1
	MAD	15.6	16.3	16.3	18.5	17.0	20.0	19.3	31.1
	Time-lag	77.7	74.8	77.2	76.1	78.0	72.3	35.8	48.6
Absolute threshold (linear interpolation)	SD	15.5	12.1	17.5	13.0	16.7	23.2	25.2	25.9
	MAD	8.9	7.4	8.2	8.9	14.8	16.3	25.2	26.7
	Time-lag	8.35		9.6		19.2		-32.1	
	min/bias	SD	2.4	SD	2.2	SD	-3.6	SD	-0.5
Relative threshold (linear interpolation)	SD	11.7	9.9	13.2	11.6	13.3	14.1	27.5	34.3
	MAD	7.4	7.4	8.9	6.7	9.6	12.6	22.9	40.0
	Time-lag	24.6		26.5		36.5		-15.1	
	min/bias	SD	-1.2	MAD	-0.9	SD	-0.2	SD	-5.8
Absolute threshold (log. interpolation)	SD	15.3	10.8	11.8	11.7	15.9	15.4	Not appl icable	
	MAD	19.3	10.4	14.1	8.9	13.3	14.1		
	Time-lag	8.7		22.2		21.3			
	min/bias	SD	2.9	SD	1.2	SD	-3.6		
Relative threshold (log. interpolation)	SD	13.3	10.0	11.7	13.1	16.3	14.3	Not applicable	
	MAD	10.4	8.9	10.4	14.8	13.3	11.1		
	Time-lag	19.6		24.4		20.7			
	min/bias	SD	2.3	SD	0.9	SD	3.1		
Highest slope	SD	15.2	12.7	18.2	14.2	18.9	12.5	15.1	12.7
	MAD	9.6	12.6	11.9	14.8	11.9	15.6	14.1	13.3

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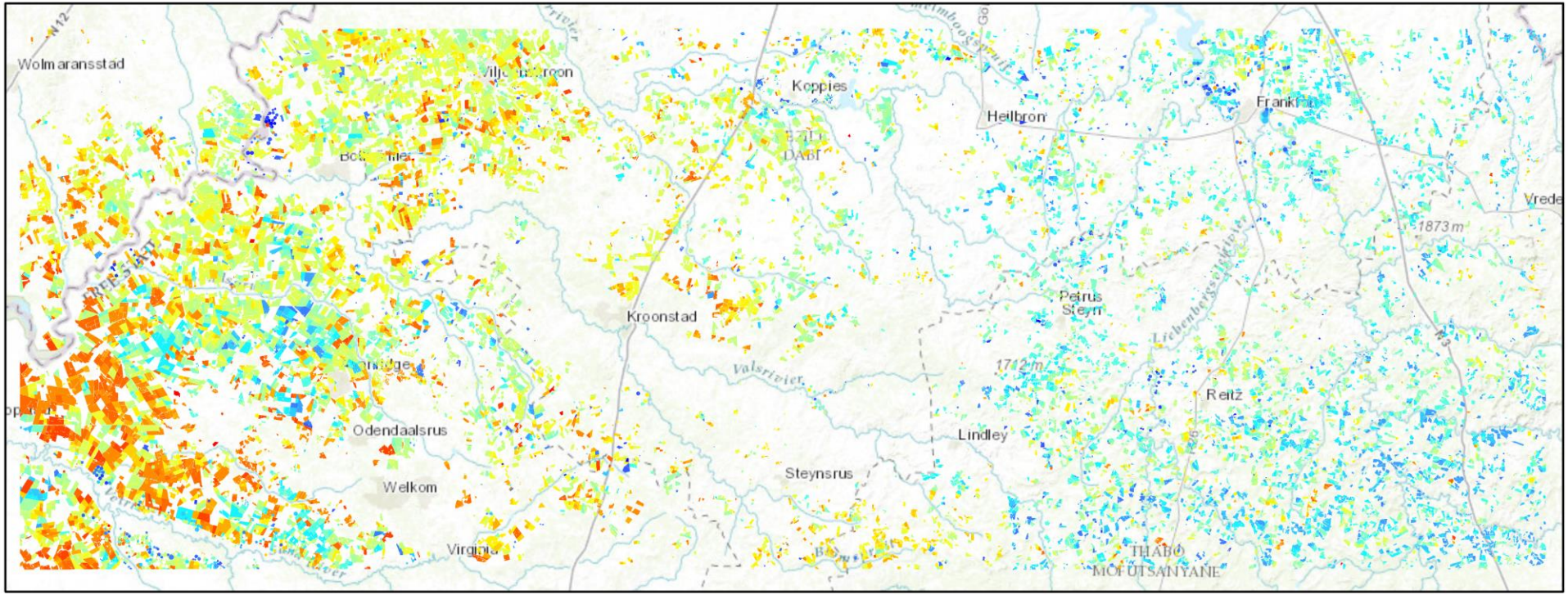
APPLICATIONS – Maize emergence date map



Emergence date

10-05 - 10-11	10-19 - 10-23	11-02 - 11-05	11-14 - 11-17	11-27 - 12-01	12-12 - 12-16	12-27 - 01-02
10-12 - 10-18	10-24 - 10-28	11-06 - 11-09	11-18 - 11-21	12-02 - 12-06	12-17 - 12-21	01-03 - 01-20
	10-29 - 11-01	11-10 - 11-13	11-22 - 11-26	12-07 - 12-11	12-22 - 12-26	01-21 - 02-18

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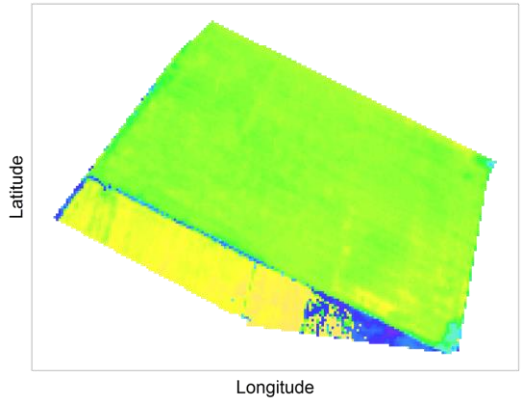
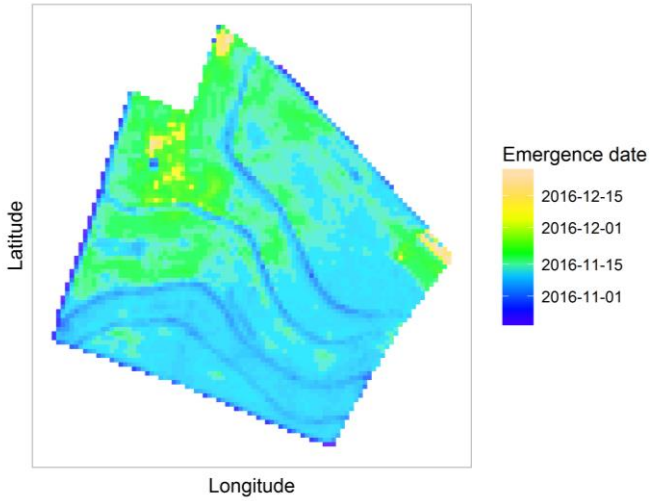
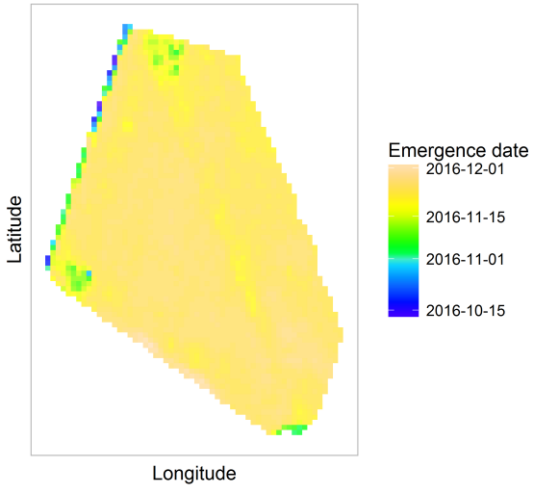
N

0 12,5 25 50 75 100 Kilometers

APPLICATIONS – heterogeneity management
precision agriculture at the pixel level







Sowing date very relevant for yield forecasting model

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CONCLUSION

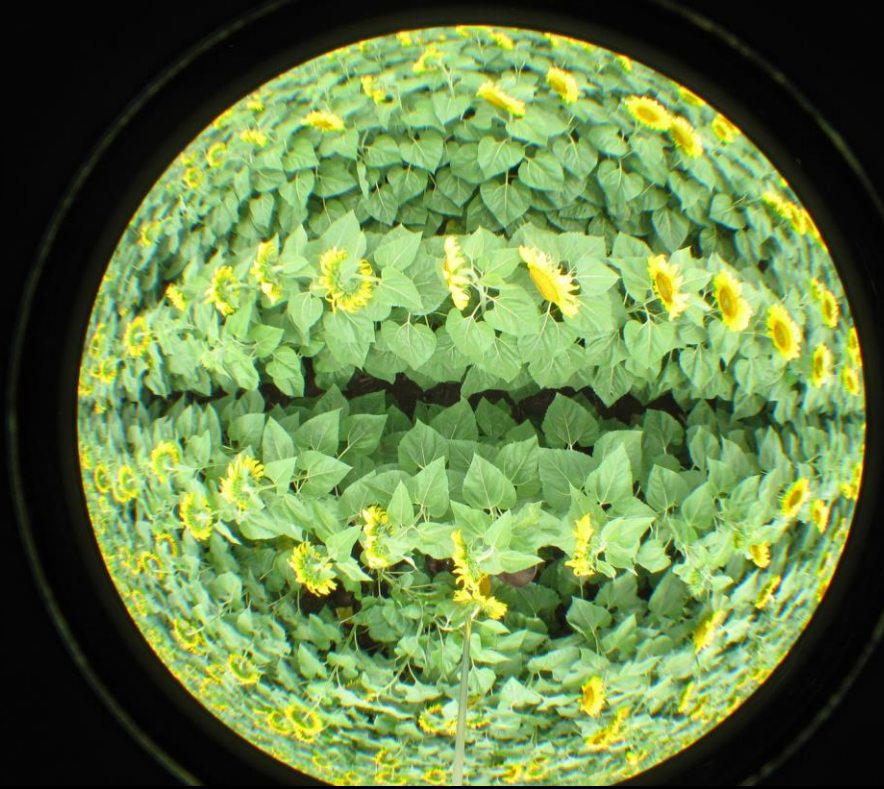
- Emergence date can be estimated with an accuracy of **±9 days using Sentinel-2a only** over a **large area with a large planting window and large range of sowing densities**

- **Relative threshold using MSAVI time series found to be the most accurate** but required to wait for the profile maximum (information delay)

  Absolute threshold using MSAVI could be used for early emergence date estimate (within the month of plant emergence) but less accurate and more sensitive to plant density

- **Dense time series using Sentinel-2a and 2b with improved cloud screening** could improve significantly these results (e.g. Sen2-Agri v.2.0)

- **In situ data availability is the main bottleneck** for developing detection algorithm of more advanced development stages (flowering, maturity) quite critical for yield.



Thank you for attention !

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