Time series from Hyperion to track productivity in pivot agriculture in Saudi Arabia

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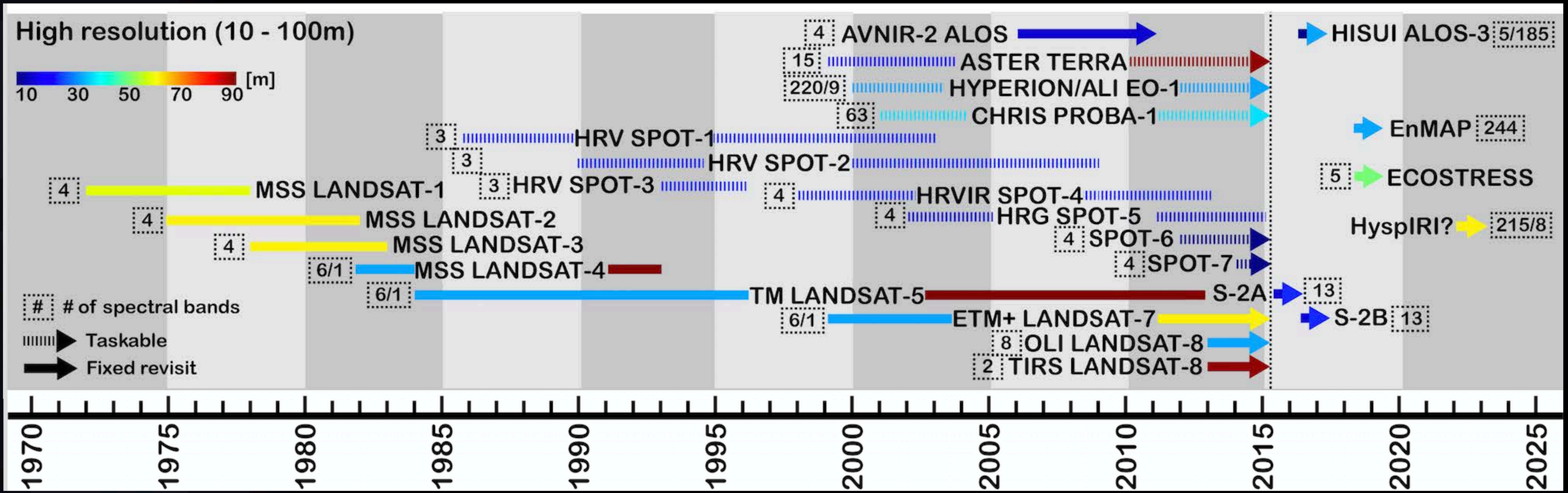
Hyperspectral satellite opportunities



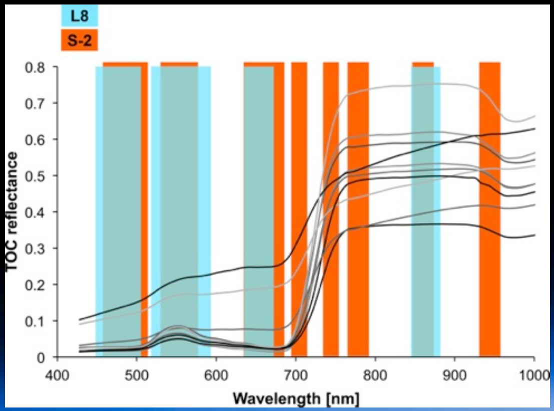
Hyperspectral Precursor of the Application M. (PRISMA) (2018-)

Hyperspectral Imager Suite (HISUI) (2019-)

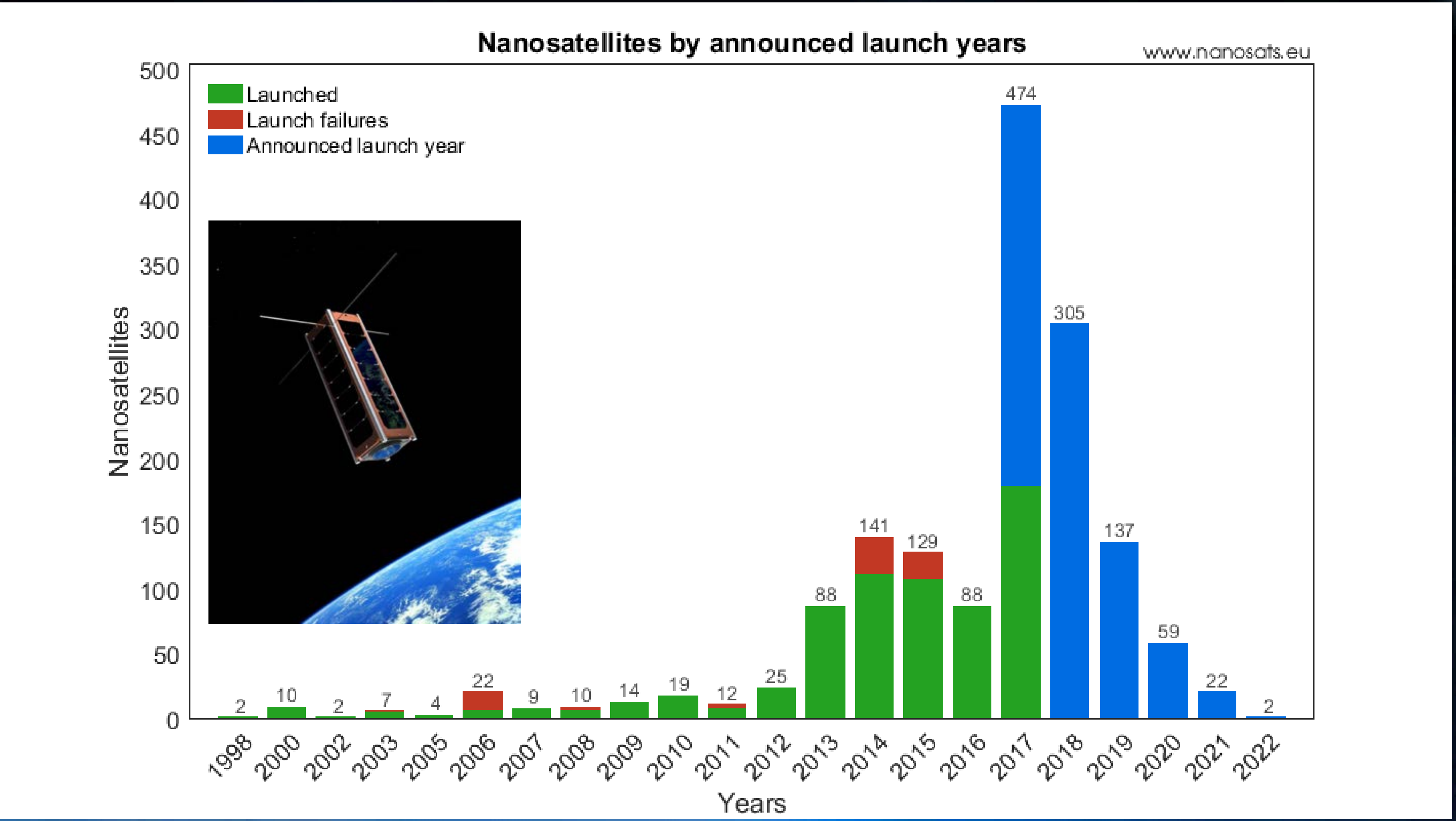
Environmental Mapping and Analysis Program (ENMAP) (2020-)

Hyperspectral Infrared Imager (HyspIRI) (2022-)

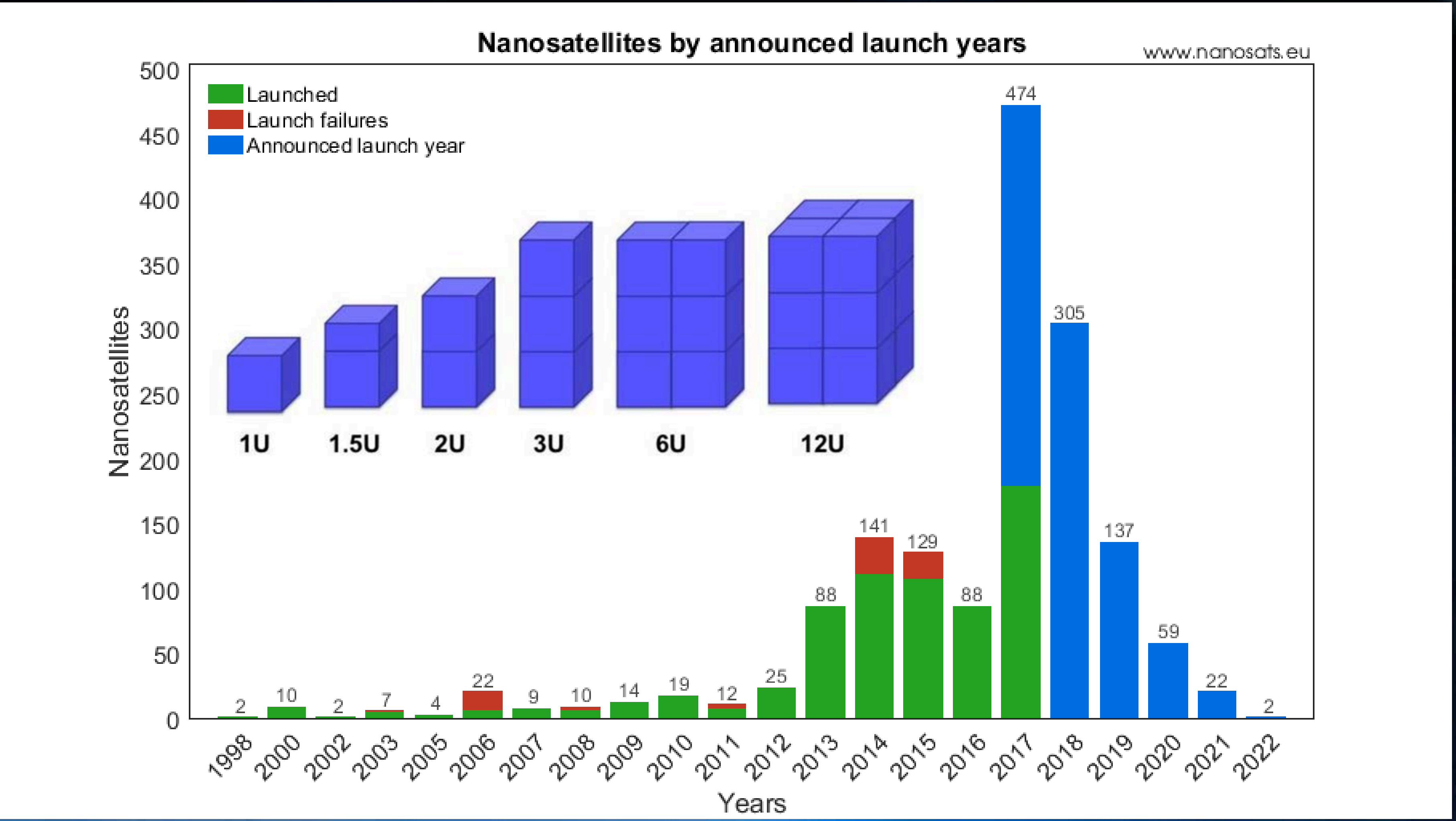
Constellations of hyperspectral Cubesats



Rise of the Cubesat



Rise of the Cubesat

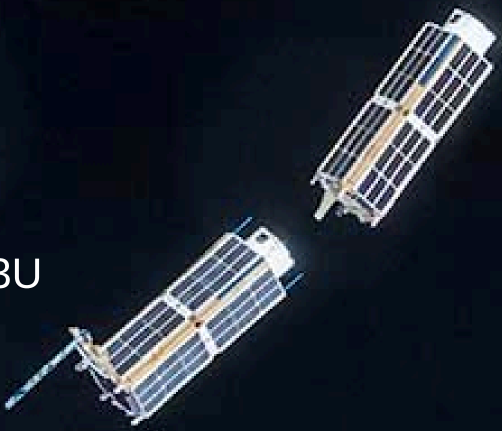


Rise of the Cubesat

The Cubesat concept: Expand observation capacity by launching small standardized (e.g., 1U: 10x10x10 cm) satellites comprised of cheap commercial-off-the-shelf components.

Significantly reduced cost, relative to conventional satellites, makes constellations of cubesats economically feasible.

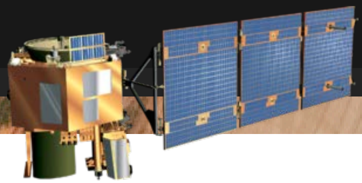
Swarms of cubesats could be the way forward to realize needed enhancements in revisit time and large area data availability.

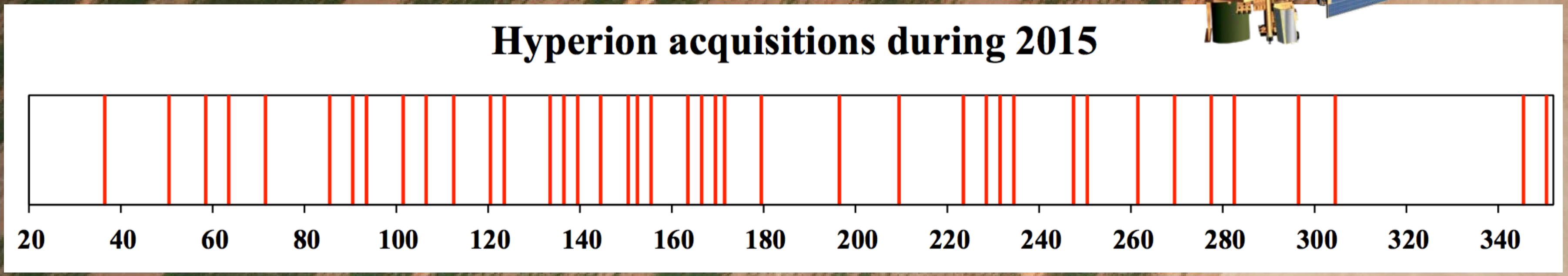


- Planet Labs (2013-): 130+ 3U (daily RGB+NIR, ~3 m)
  - Astro Digital (2017-): Twenty 6U (3-4 day multi-spectral, 2.5 m)
    - Planetary Resources (2019-): Ten 12U (weekly hyperspectral, 10-15 m)

Planet's launch of 88 cubesats on Feb 14, 2017

Objectives

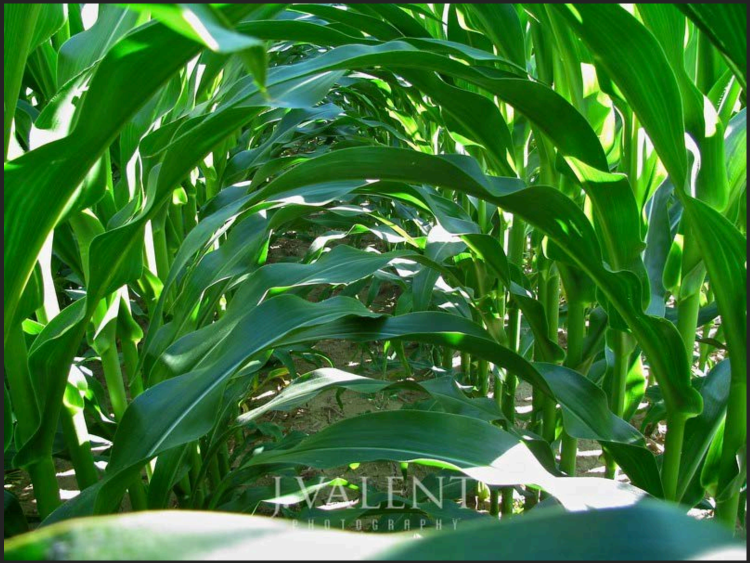




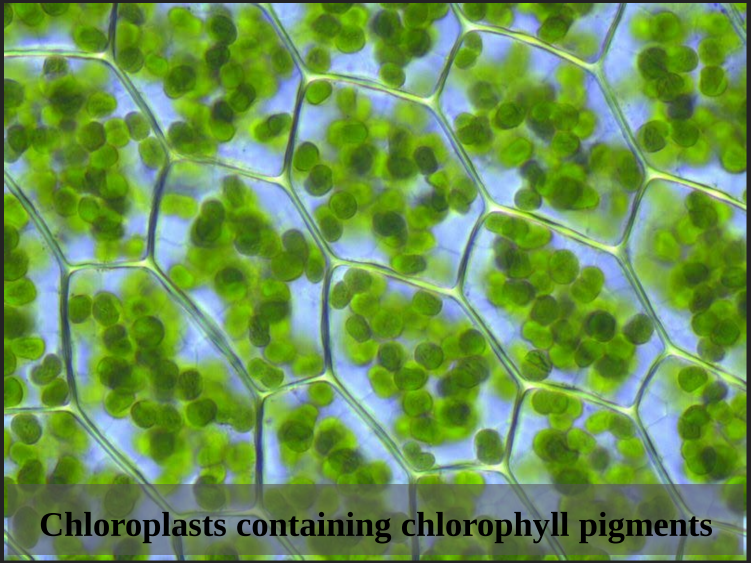
- Investigate the potential benefit of high frequency hyperspectral time series data for vegetation monitoring and characterization
- Track high frequency dynamics in vegetation growth and condition through correlated vegetation metrics (i.e., LAI and chlorophyll) retrievable from remote sensing observations via machine-learning
- Investigate the utility of the time series data for estimating productivity and crop yield

Monitoring vegetation condition and productivity from space

Leaf Area Index [m^2 m^{-2}]



Leaf Chlorophyll [μg cm^{-2}]



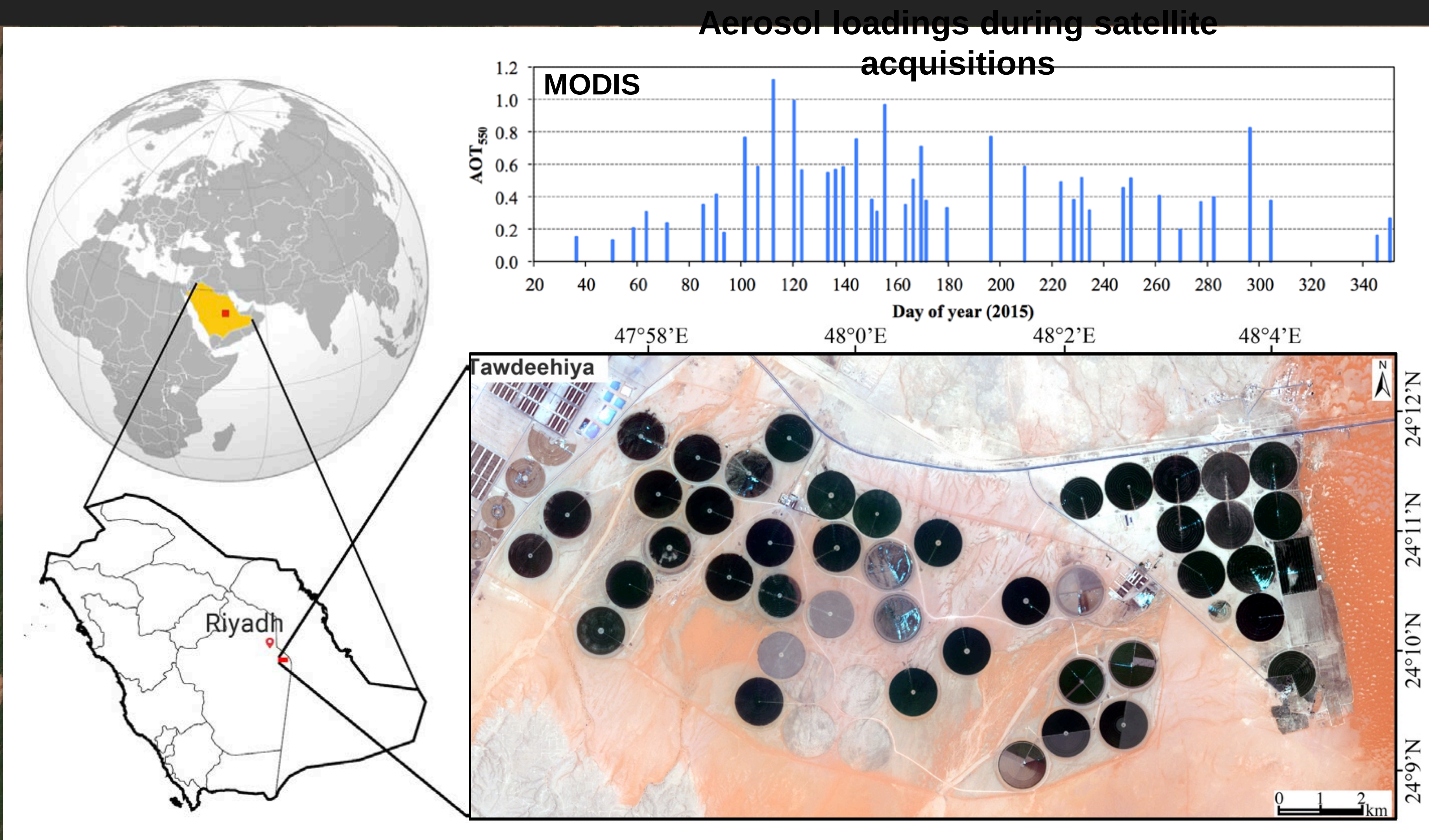
Chloroplasts containing chlorophyll pigments

In combination, LAI and leaf chlorophyll serve as key observable metrics for vegetation growth and health

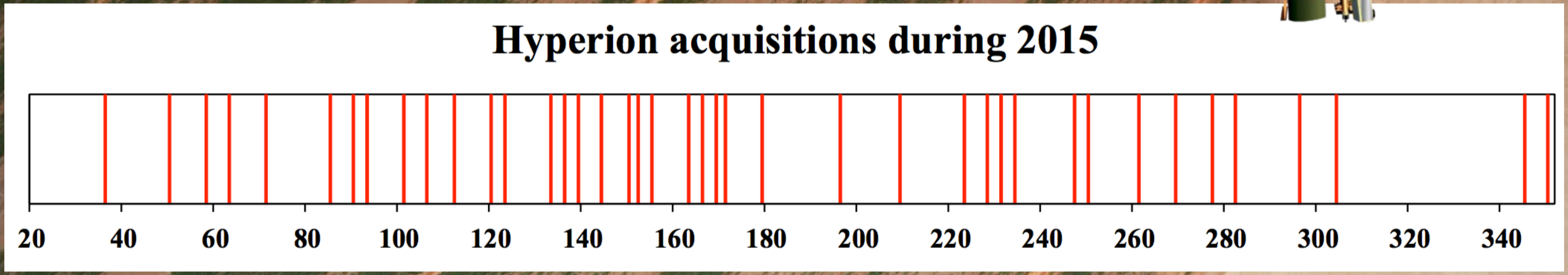
The availability of spatially distributed (and timely) information on these metrics has significant utility in precision farming and management

LAI and leaf chlorophyll are related to crop productivity and may be used to assess actual yield potentials taking into account crop limiting factors (e.g., water and nutrients)

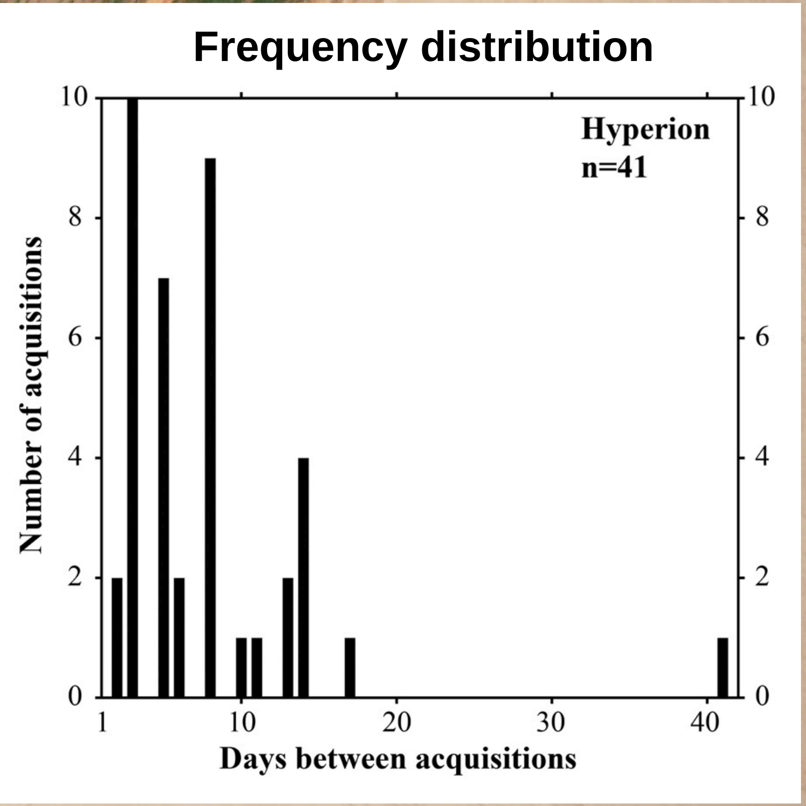
Study region



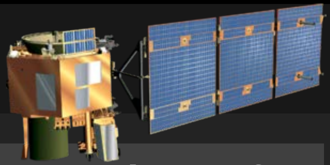
EO-1 Hyperion data



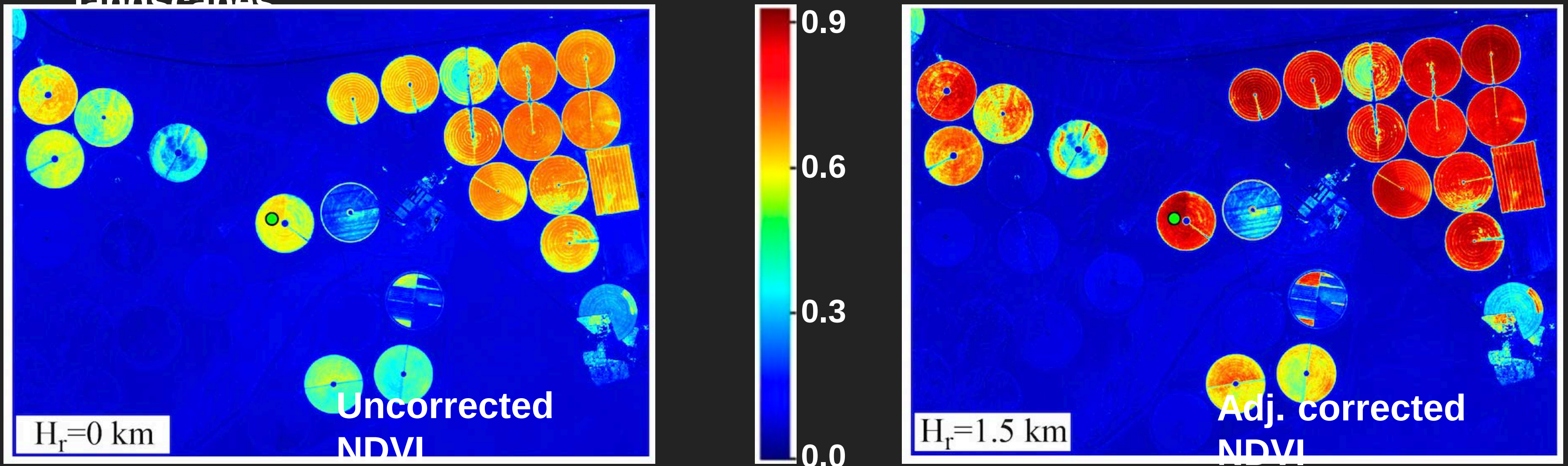
- 196 calibrated bands (10 nm) with a 30 m nadir ground resolution
- Off-nadir viewing capability (±22° roll angle) facilitates up to five acquisitions during a 16-day period
- The time series data were corrected to a common sensing geometry via an implementation of PROSAIL

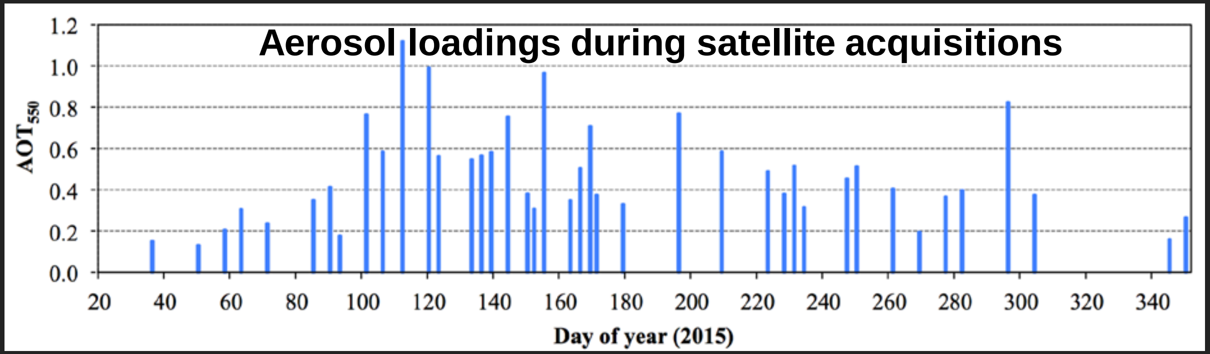


EO-1 Hyperion data



- **Atmospheric correction was done using FLAASH. Including corrections for adjacency effects that can be substantial over high contrast surface reflectance landscapes.**

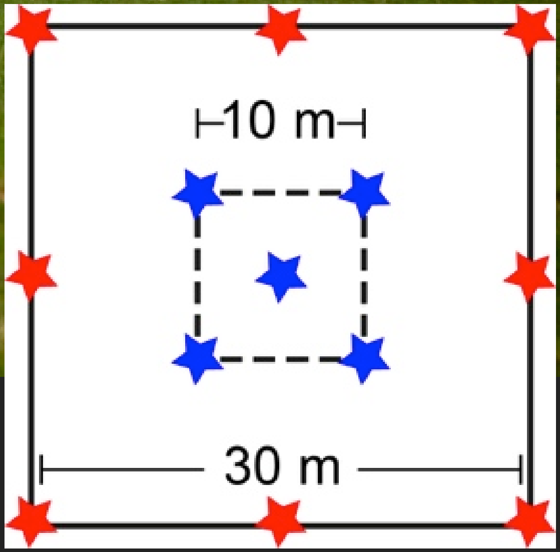




- **A spectral polishing process and minimum noise fraction transformation were applied in order to smooth reflectance profiles and reduce striping and smile effects.**

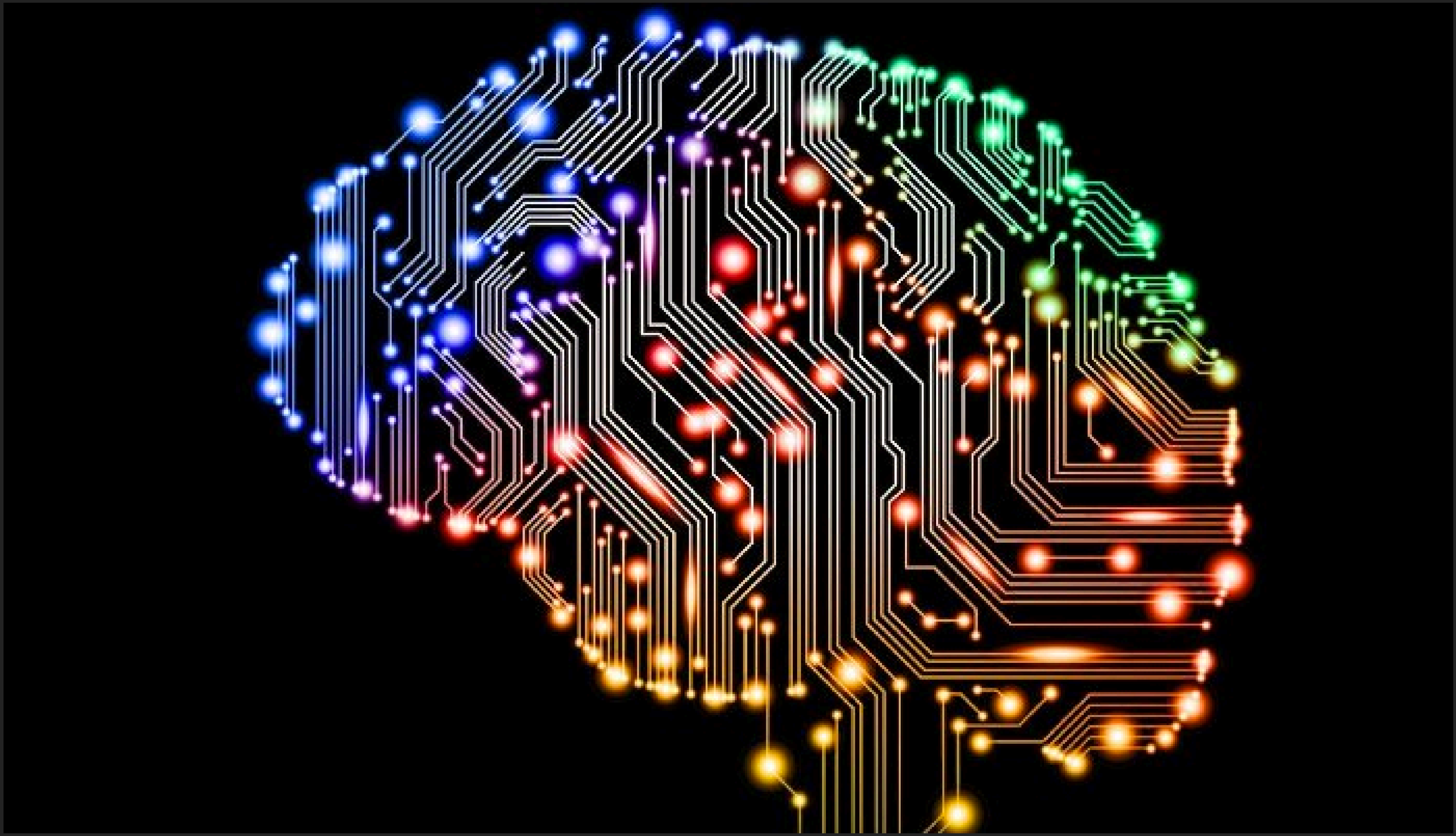
In-situ data collection

Campaign dates (2015)	DOY	n	LAI	Chl$_l$
Feb 16-18 28	47-49	16/15	1.9±1.1	60±16
March 23-24	82-83	18/17	3.6±0.9	54±20
April 13-15	103-105	25/19	2.8±1.8	43±18
June 1-3	152-154	13/13	4.2±1.3	46±9
Oct 6-8	279-281	4/3	2.6±1.9	51±13

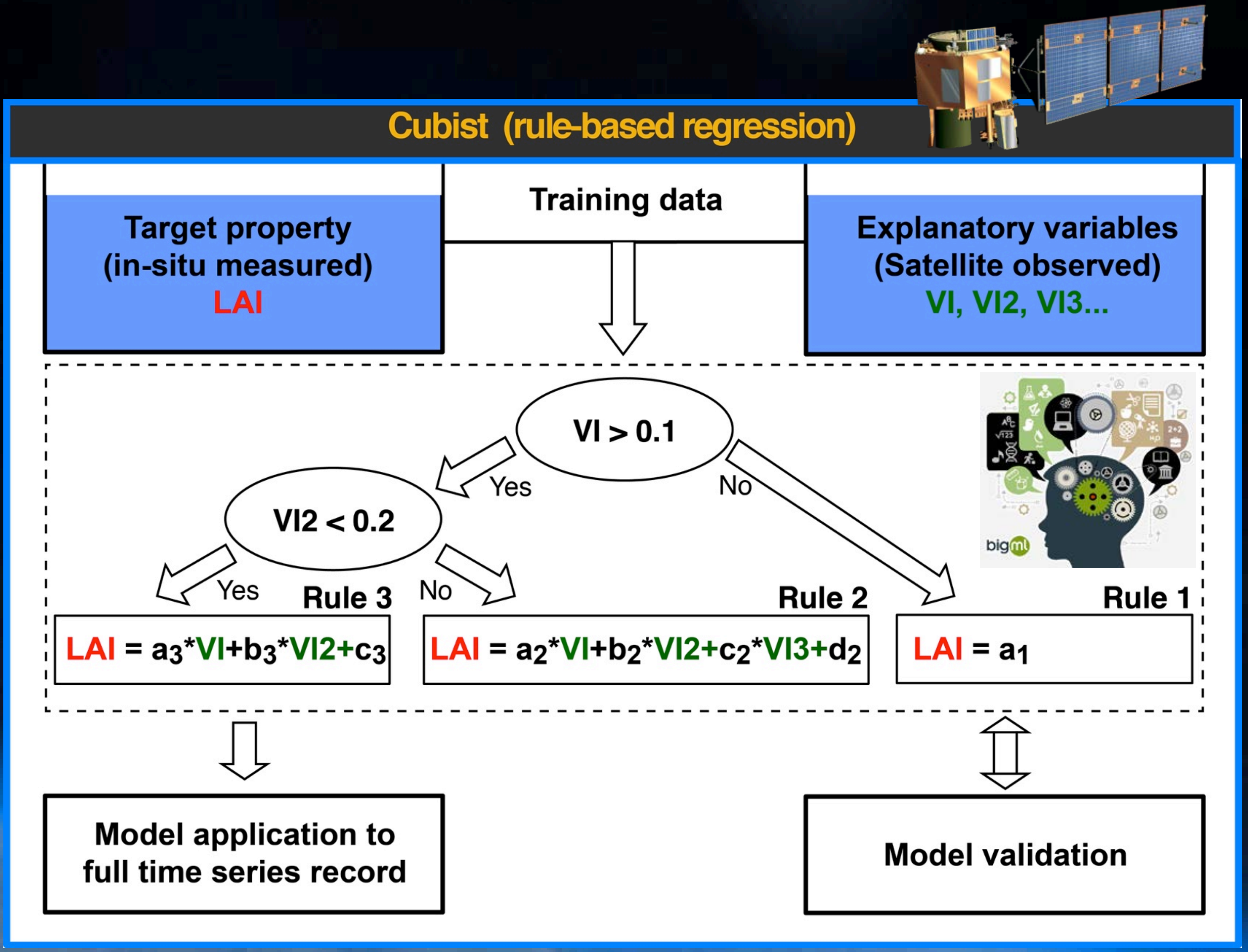


Hyperion collections for model training and validation

Cubist machine-learning



Cubist machine-learning



Explanatory variables

Group	Category	Variables
Group 1	Green biomass	NDVI, EVI, SAVI…
Group 2	Green biomass	SR, GRVI, RSR...
Group 3	Bio-chemical	RENDVI, VREI2…
Group 4	Bio-chemical	VREI1, MTCI...
Group 5	LUE	PRI, SIPI, CRI2…
Group 6	First derivative	D02, D32, DMAX22..
Group 7	First derivative	DND1, DND2…
Group 8	Continuum removed	ANCB1, ANCB2…

$$NDVI = (R_{872} - R_{661})/(R_{872} + R_{661})$$

$$SR = R_{872}/R_{661}$$

$$RENDVI = (R_{752} - R_{702})/(R_{752} + R_{702})$$

$$MTCI = (R_{742} - R_{702})/(R_{702} - R_{661})$$

$$PRI = (R_{529} - R_{569})/(R_{529} + R_{569})$$

$$D_{732} = (R_{742} - R_{722})/(742 - 722)$$

$$DND1 = (D_{742} - D_{529})/(D_{742} + D_{529})$$

$$ANCB1 = AUC_{610-742}/(1 - CR_{671})$$

Multi-spectral versus hyperspectral evaluations

Group 1	**Green biomass**	NDVI, EVI, SAVI…	**Hyperion**	**Sentinel-2**	**Landsat-8**
Group 2		SR, GRVI, RSR…	**Hyperion**	**Sentinel-2**	**Landsat-8**
Group 3	**Bio-chemical**	RENDVI, VREI2…	**Hyperion**	**Sentinel-2**	
Group 4		VREI1, MTCI…	**Hyperion**	**Sentinel-2**	
Group 5	**LUE**	PRI, SIPI, CRI2…	**Hyperion**	Sentinel-2	
Group 6	**First derivative**	D02, D32, DMAX22..	**Hyperion**		
Group 7		DND1, DND2…	**Hyperion**		
Group 8	**Continuum removed**	ANCB1, ANCB2…	**Hyperion**		

Cubist model results (Leaf Chl and LAI)

MTVI2 | GRVI | RSR | VREI1

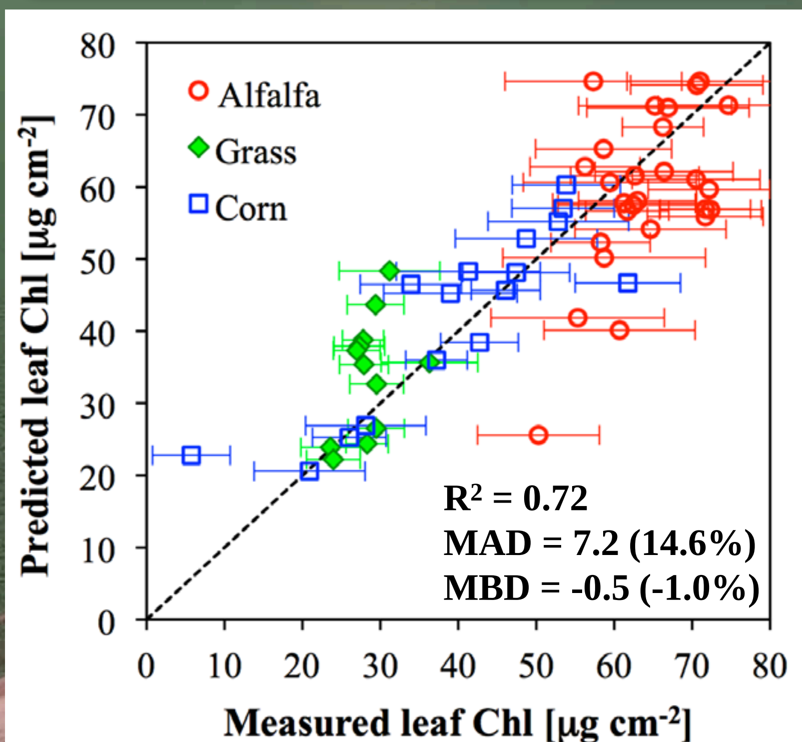
D12

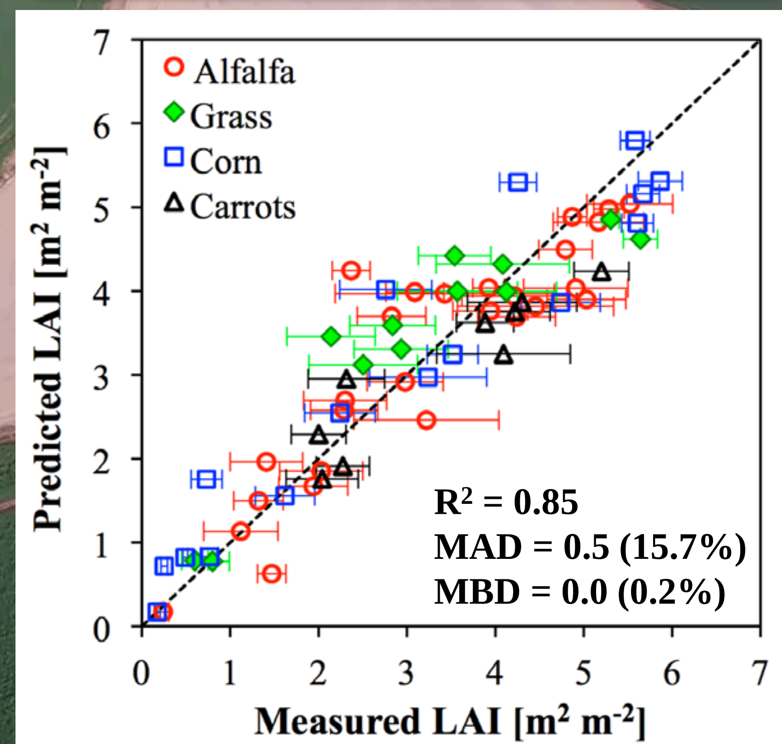
NDVI | RSR | VREI1

CRI1 | D32

Leaf Chl = -145.9 + 84.4×D12 - 90.6×RSR - 146.5×MTVI2 + 173.8×VREI1 + 100.4×NLI + 14×GRVI

LAI = -1.79 + 1.52×D32 + 6.11×MTVI2 - 1.6×ARVI - 0.017×CRI1 - 0.13×NDVI + 0.11×VREI1 + 0.04×RSR



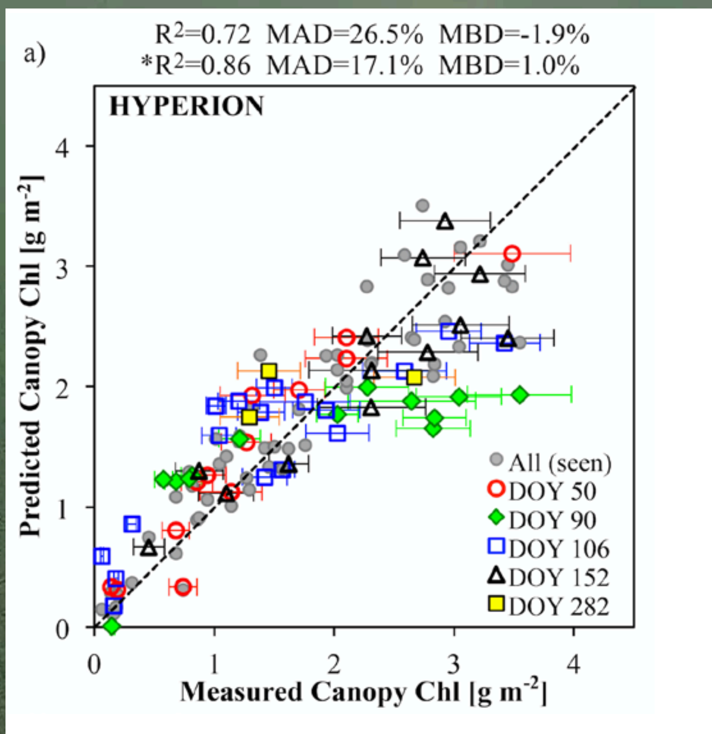


Canopy chlorophyll (i.e., LAI×Chl) validation

Hyperion

GNDVI | NDRE | VREI1

PRI4 | DND1 | ANCB



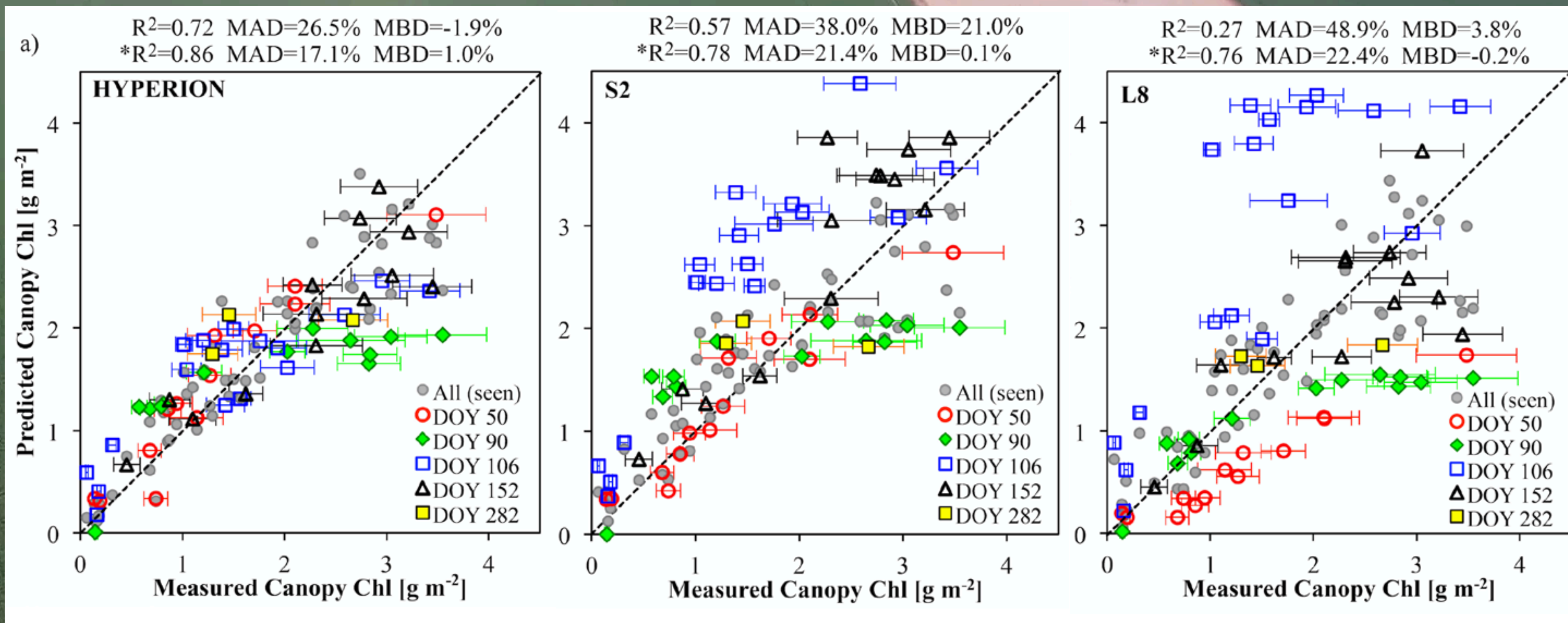
R^2	MAD	MBD
0.72	26.5 %	-1.9 %

Canopy chlorophyll (i.e., LAI×Chl) validation

Hyperion			
GNDVI		NDRE	VREI1
PRI4		DND1	ANCB

Sentinel-2			
GNDVI	GRVI	MREN DVI	
ARI2			

Landsat-8			
NDVI	GRVI		

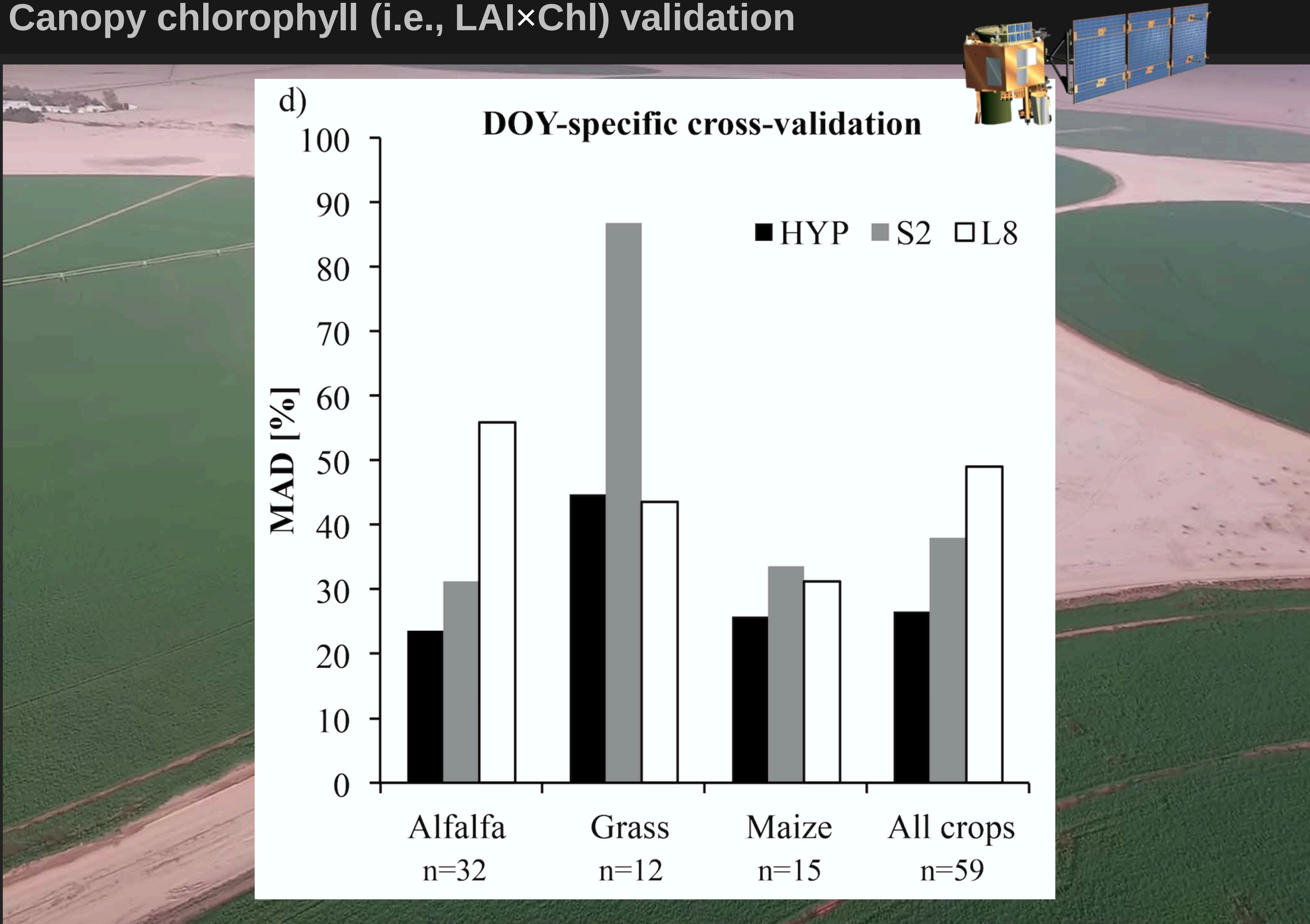


R^2	MAD	MBD
0.72	26.5 %	-1.9 %

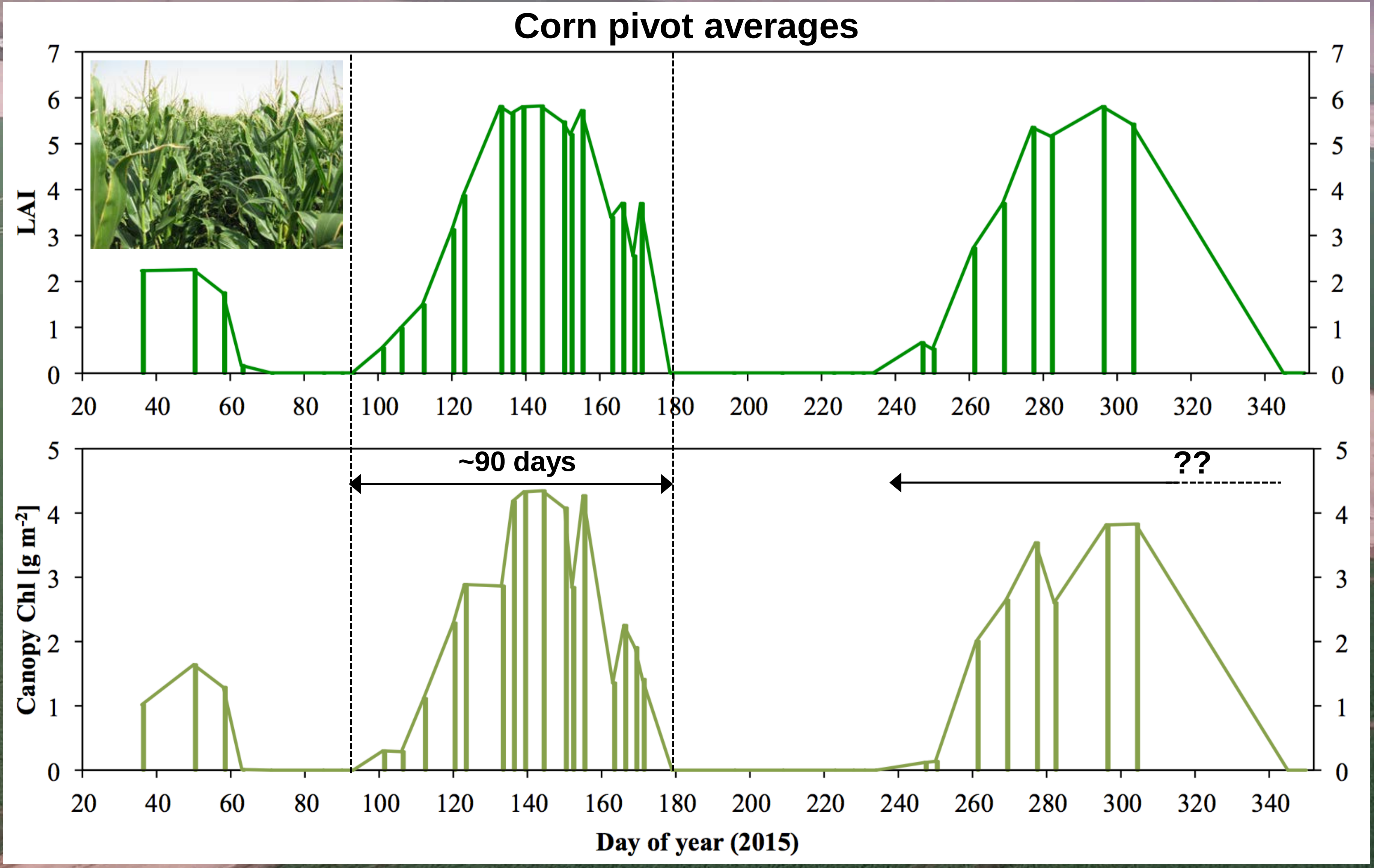
R^2	MAD	MBD
0.57	38.0 %	21.0 %

R^2	MAD	MBD
0.27	48.9 %	3.8 %

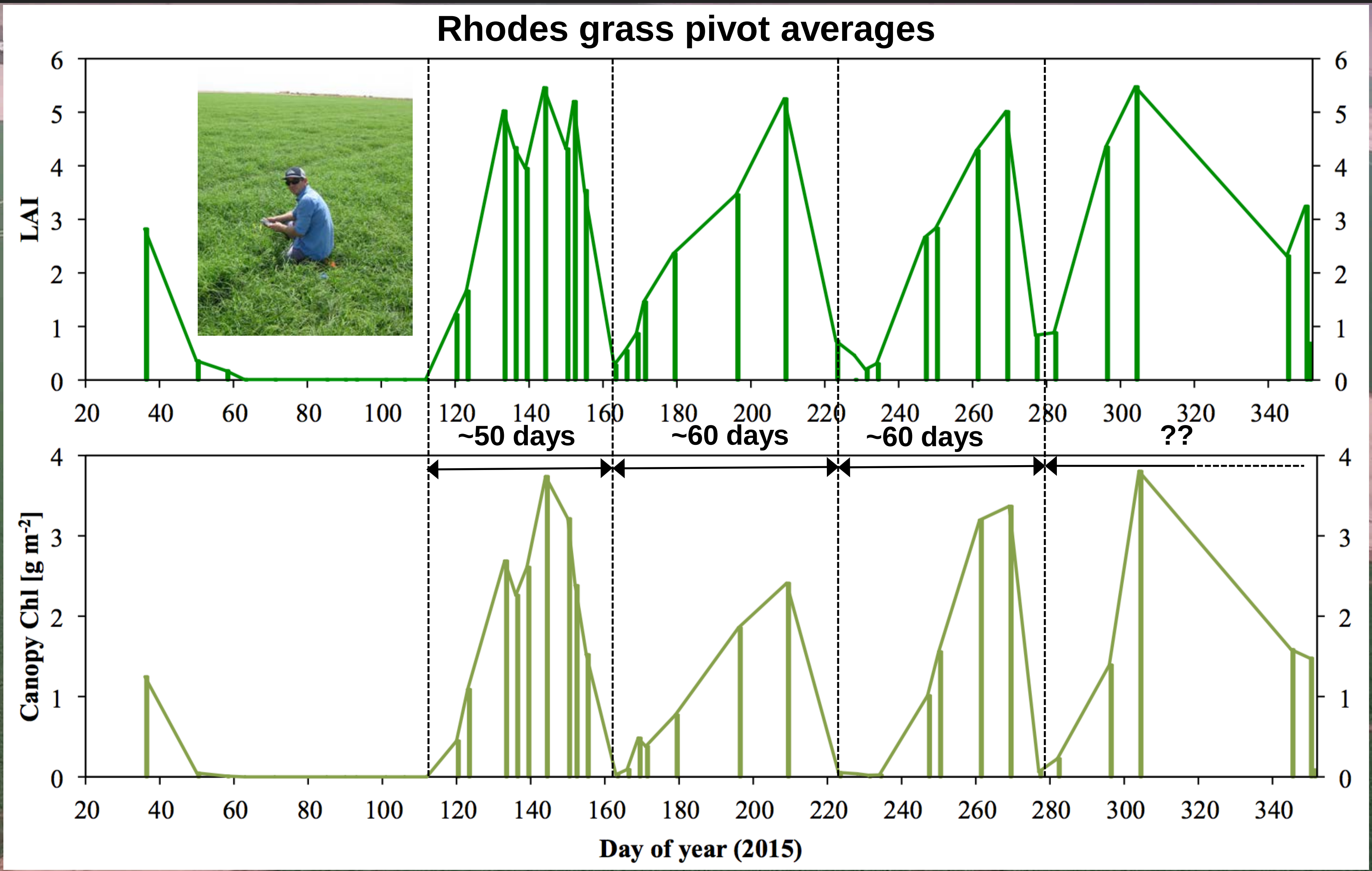
Canopy chlorophyll (i.e., LAI×Chl) validation



Time series of LAI and canopy chlorophyll



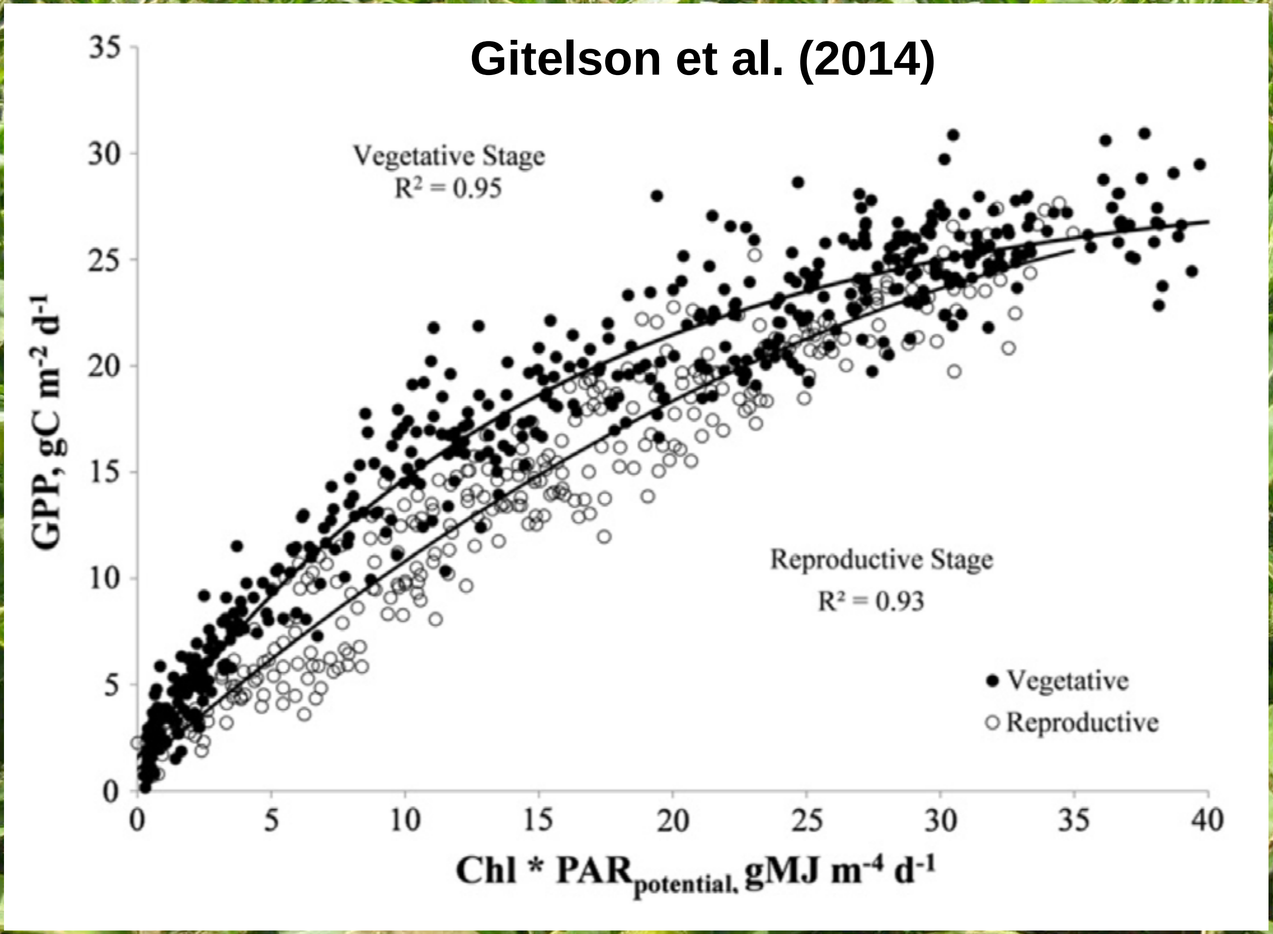
Time series of LAI and canopy chlorophyll



Utility for yield prediction

$$GPP = -0.014\left(Chl_c \times PAR_p\right)^2 + 1.17\left(Chl_c \times PAR_p\right) + 2.126$$

$$Yield = \left(\sum_t^n GPP_t\right) \times CUE \times RS \times HI \times 2.2$$



Utility for yield prediction

$$\text{Yield} = \left(\sum_t^n \text{GPP}_t\right) \times \text{CUE} \times \text{RS} \times \text{HI} \times 2.2$$

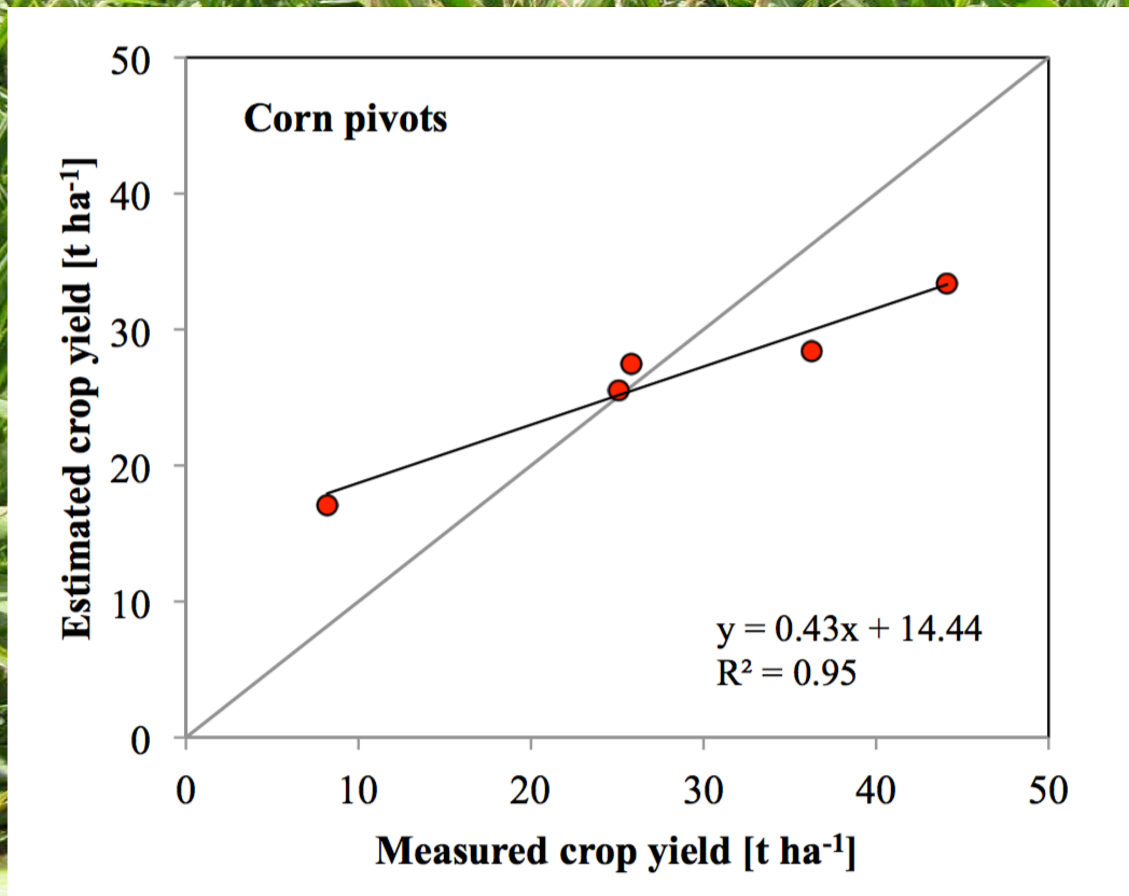
t=start of growing season

n=end of growing season

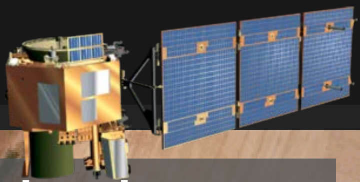
CUE=carbon use efficiency

RS=ratio of aboveground NPP to total NPP

HI=harvest index



Conclusions



- Hyperspectral model regressions for canopy chlorophyll estimation were shown to be more transferable over time and space domains than models based on multi-spectral (i.e., S-2 and L8) VI configurations.

- Hyperion tasking over a spatially limited agricultural region facilitated a rare record of very high frequency hyperspectral observations needed to capture key phenological features of the studied crops.

- Resulting time series of canopy chlorophyll and GPP were translated into crop yield estimates that were shown to correlate well with observations.

- A constellation of several sensors (e.g., Cubesats) will be needed to achieve the same observing capacity for large scale monitoring purposes.

- However data from such platforms must complement, and not replace, the high quality imagery acquired by conventional large satellite systems. The relatively low radiometric accuracy and cross-sensor inconsistencies represent key challenges in realizing the full potential of Cubesat systems as a game changer in Earth observation.

Thank you!

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كاوست
KAUST

Ceres 1 (Arkyd-100)	Planetary Resources	Company	US	12U	2018-12-31	Constellation of Arkyd 100 spacecraft. With just 10 satellites, the Ceres constellation provides weekly hyperspectral and mid-wave infrared data for any spot on Earth at a lower cost than existing multispectral data.

CubeSat Commercial Constellations and Investments

Organization	Launched / Planned size	First launch	Form factor	Field	Funding	Technical and comments	Image
Planet	267 / 150+	2013	3U	Earth observation	$183 million	29 MP sensor taking images with 3.7 m ground resolution and swath of 24.6 km × 16.4 km from 475 km altitude.	
Spire	37 / 100+	2013	3U	Weather / AIS / ADS-B	$69.5 million	Measure change in GPS signal after passing atmosphere to calculate precise profiles for temperature, pressure, humidity.	
Planetary Resources	2 / 10	2014	12U	Earth observation	$50+ million	Visible-NIR 40 channel hyperspectral imager with 10 m resolution. Midwave infrared imager (MWIR) in 3-5 μm with 15 m resolution.	
Astro Digital (Aquila)	2 / 10+20	2014	6U / 16U	Earth observation	$16.7+ million	6U has 22 m resolution in RGB and NIR. 16U has 2.5 m resolution in RGB, red edge, and NIR using one 70 MP sensor.	
Sky and Space Global	3 / 200	2017	3U	IoT / M2M / Voice	$11.5 million	Plans to use inter-satellite links. Satellites outsourced from GomSpace.	
GeoOptics	1 / 6	2017	6U	Weather	$5.15 million	Satellites outsourced from Tyvak.	
Kepler Communications	0 / 140	2017	3U	IoT / M2M	$5 million	Monthly fee based on the data amount. Hope to achieve rates of 1-40 Mbps. Clyde Space will provide at least the first 2 sats.	
Astrocast (ELSE)	0 / 64	2017	3U	IoT / M2M	$5.85 million	Demonstration mission in Q4 2017. 8 satellites in Q4 2018. Targeting L-band. Inter-satellite links. NanoSpace propulsion.	
Capella Space	0 / 40	2017	12U	SAR	$12+ million	Resolutions from 1 m (1600 km^2) to 30 m (27,000 km^2). Every 3-6 hours globally and 45 min in equatorial regions, improving to every hour in 3-5 years.	
PlanetiQ	0 / 18	2017	6U	Weather	$5+ million	Based on GPS radio occultation. Will have microwave spectrometer & radiometer. Blue Canyon Tech builds satellites.	
Magnitude Space	0 / 48	2017	6U	IoT / M2M	$1 million	Send small packets of data (140 characters, accompanied by time-stamp, identifier and location).	
Hera Systems	0 / 9-48	2017	12U	Earth observation	$4.2+ million	Capable of 1-meter resolution with 22-kilogram form factor.	

Time series of LAI and canopy chlorophyll