UNIVERSITÄT BONN

Transdisciplinary Research Area
Innovation and Technology for
Sustainable Futures (TRA 6)

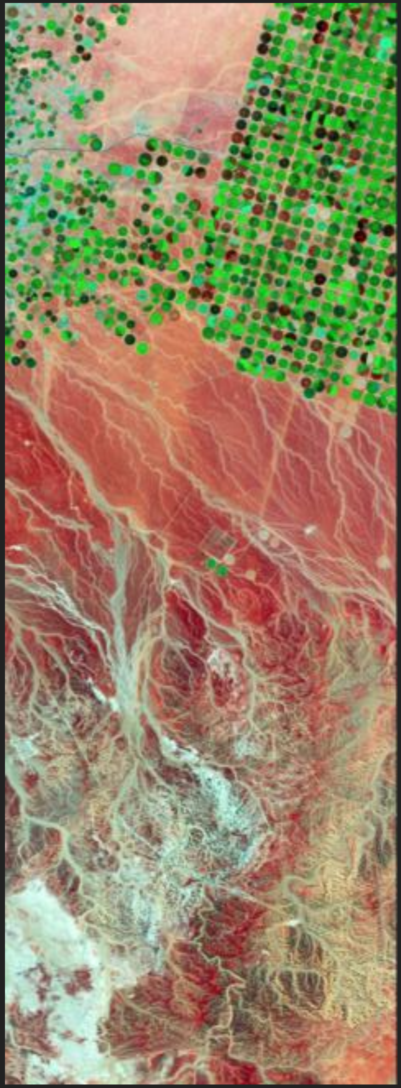
WELCOME TO THE TRA 6 LECTURE SERIES INNOVATION PATHWAYS TO SUSTAINABILITY

DATA-DRIVEN AGRICULTURE: A NEW PATHWAY TOWARDS SUSTAINABILITY IN OUR FOOD (AND WATER) SYSTEMS?

MATTHEW MCCABE, PROFESSOR OF REMOTE SENSING AND WATER SECURITY, KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

MODERATORS:
JAN BÖRNER, JOACHIM VON BRAUN, TRA 6-SPEAKERS
OLENA DUBOVYK, FACULTY OF MATHEMATICS AND NATURAL SCIENCES, UNIVERSITY OF BONN

DATA DRIVEN AGRICULTURE: A NEW PATHWAY TOWARDS SUSTAINABILITY

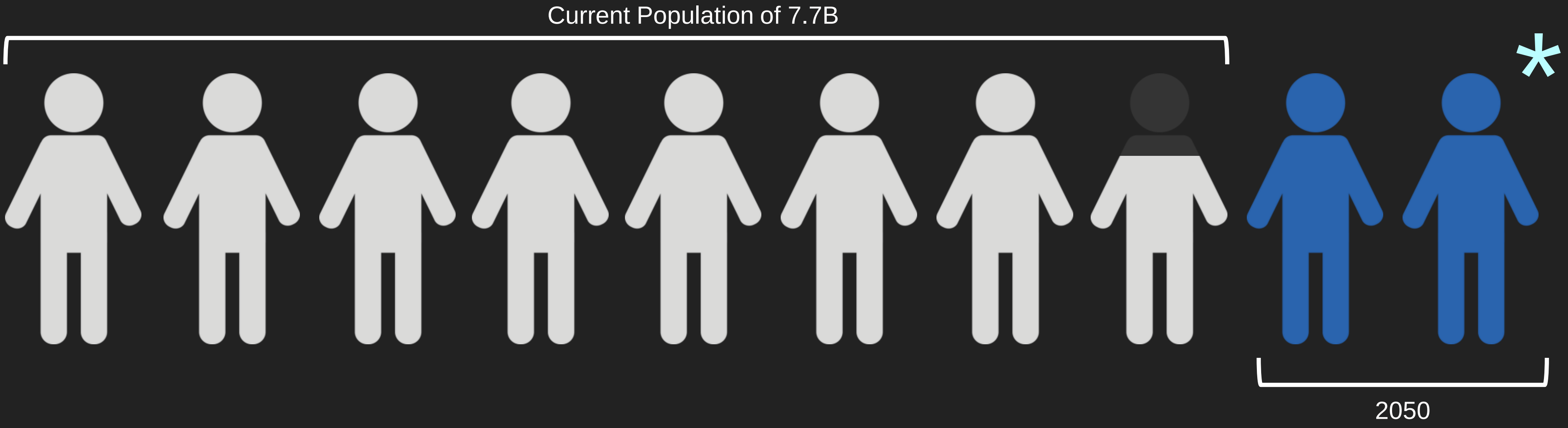


PROF MATTHEW MCCABE

KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KAUST

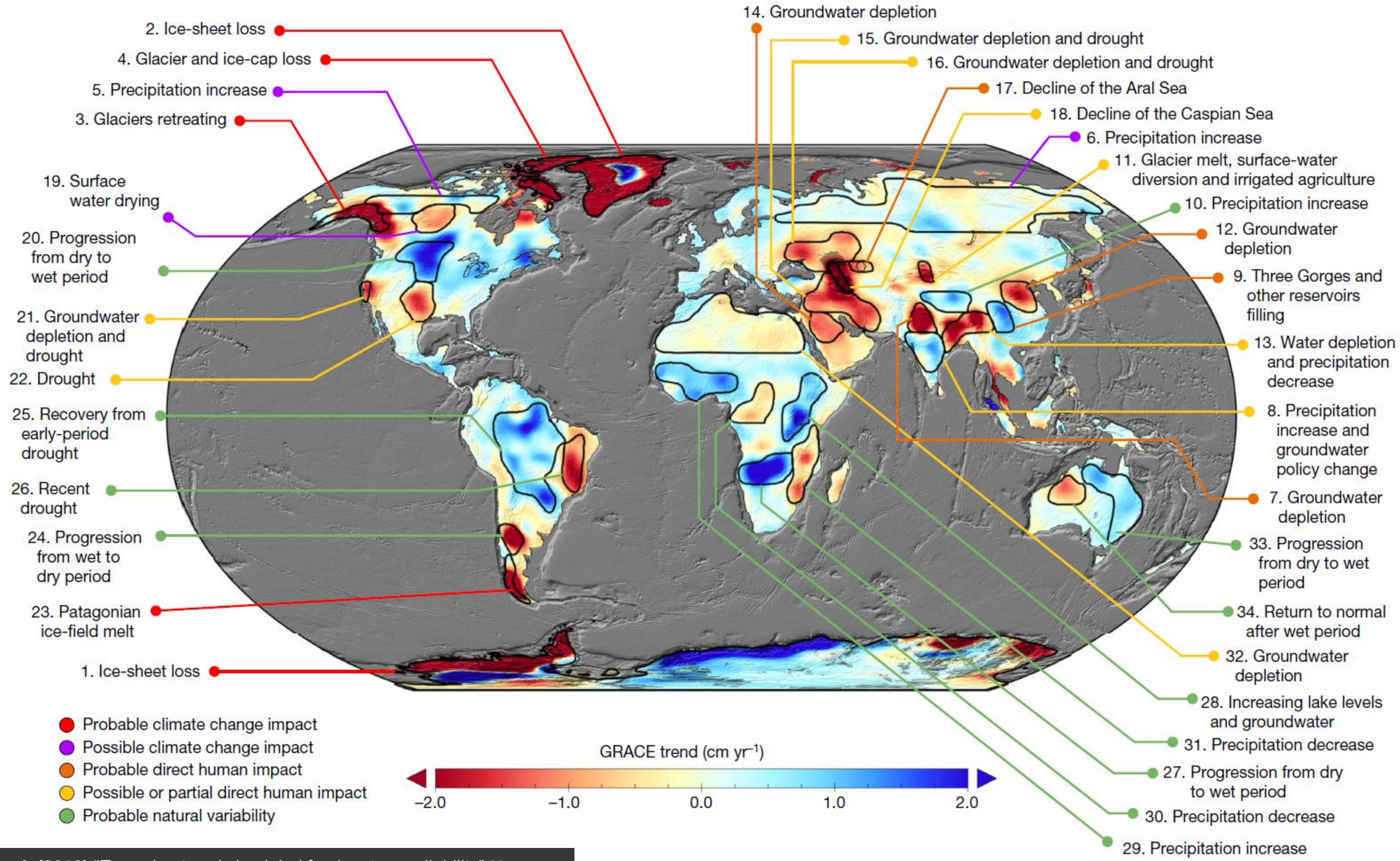
10 BILLION by 2050



*an extra 2 billion people will require a doubling of food production

How will we achieve food (and water) security?

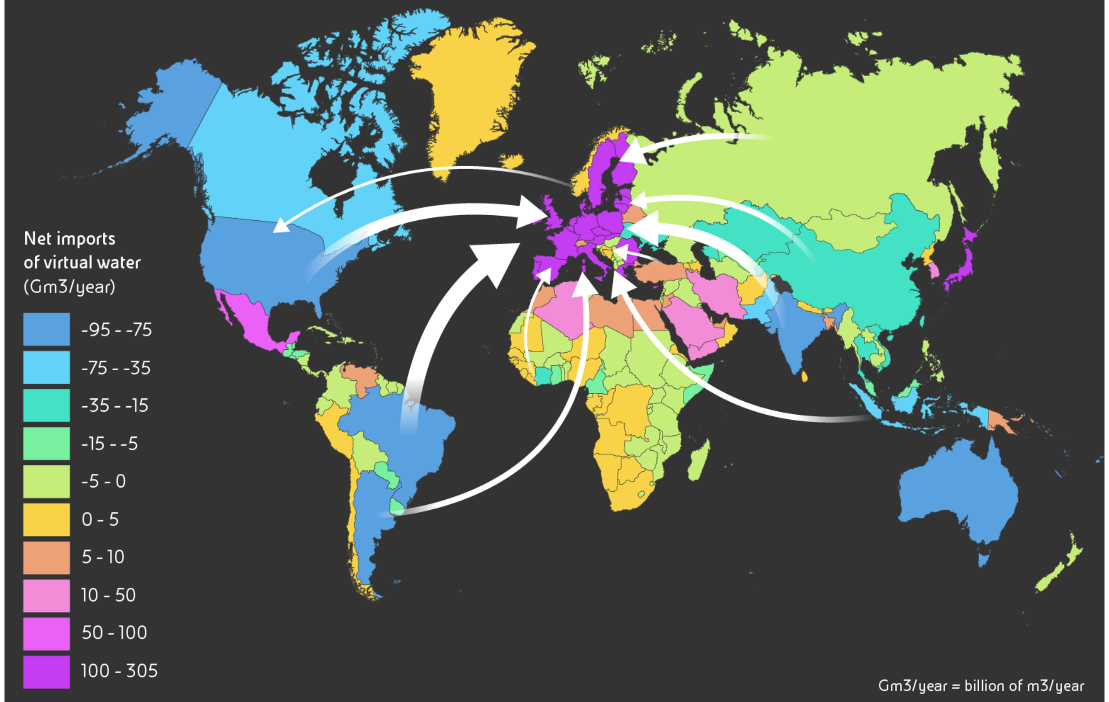

social
impact
environmental
impact
economic
impact



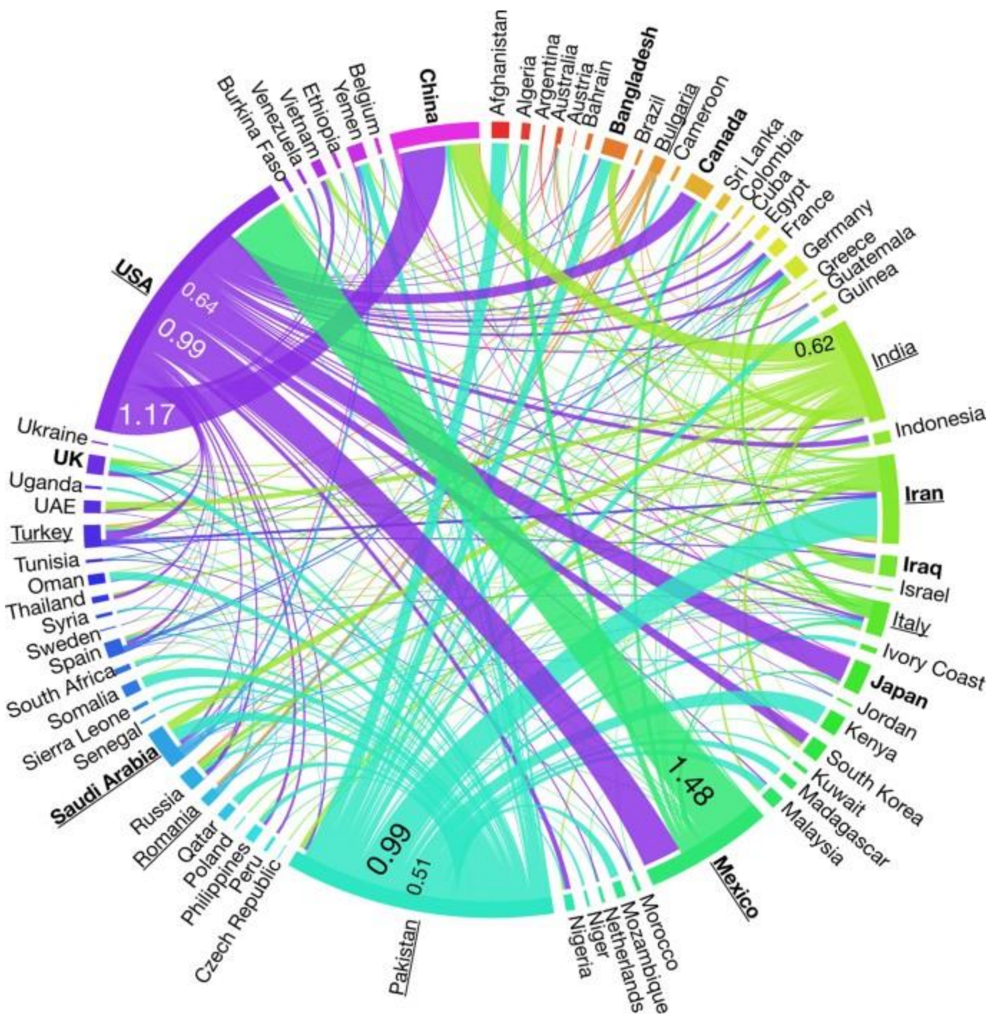
Rodell et al. (2018) “Emerging trends in global freshwater availability” **Nature**

Virtual water balance by country and flows

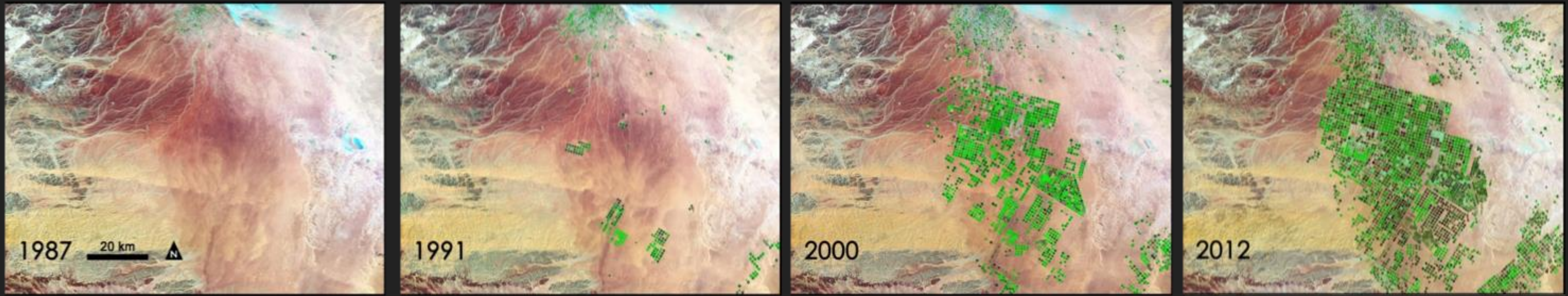
The map shows the virtual water balance by country and the direction of gross "flows" of virtual water connected with the trade in agricultural and industrial products in the period 1996-2005. Only the biggest gross flows are shown (> 15 billion cubic meters a year); the thicker the arrow, the greater the "flow" of virtual water.

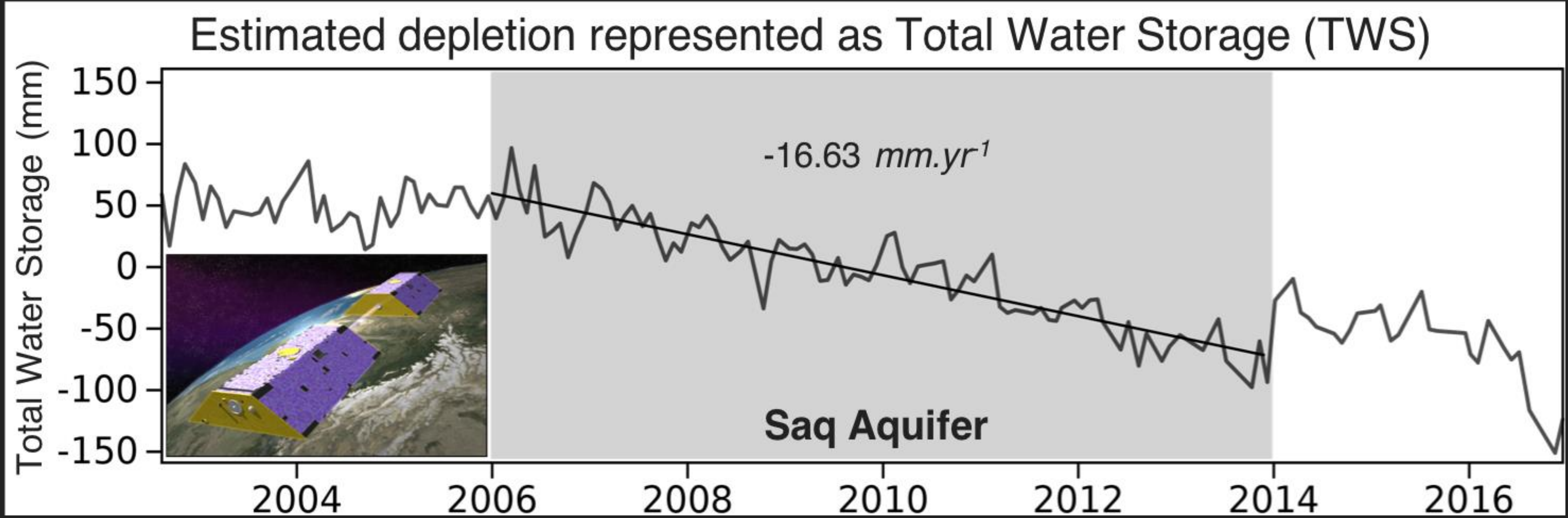


Source: World Energy #46; Mekonnen and Hoekstra (2011) "The green, blue and grey water footprint of crops and derived crop products", Hydrology and Earth System Sciences



Dalin et al. (2017) "Groundwater depletion embedded in international food trade" **Nature**





Lopez et al. (2017) “Evaluating the hydrological consistency of evaporation products using satellite-based gravity and rainfall data” **HESS**

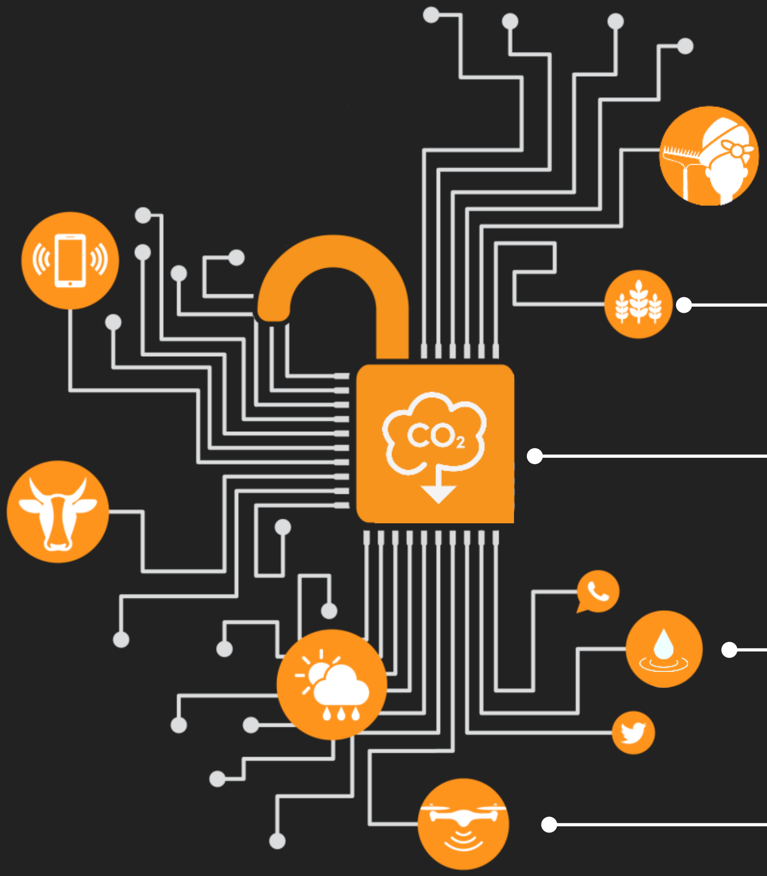
There is no silver bullet

Sustainable Intensification

i.e. do more, with less

Cassman and Grassini. (2020) “A global perspective on sustainable intensification research” **Nature Sustainability**

A Digital Transformation?



agriculture employs > **1.3 billion** people and is a \$2.4 trillion dollar industry

#1 contributor to landfill (up to 1/3 of food is wasted)

#2 largest emitter of GHGs

#1 water user (up to 70% of freshwater)

information poor, but increasingly data rich

Figure adapted from bigdata.cgiar.org/inspire/

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Hydrology and Earth System Sciences
Open Access

The future of Earth observation in ~~hydrology~~

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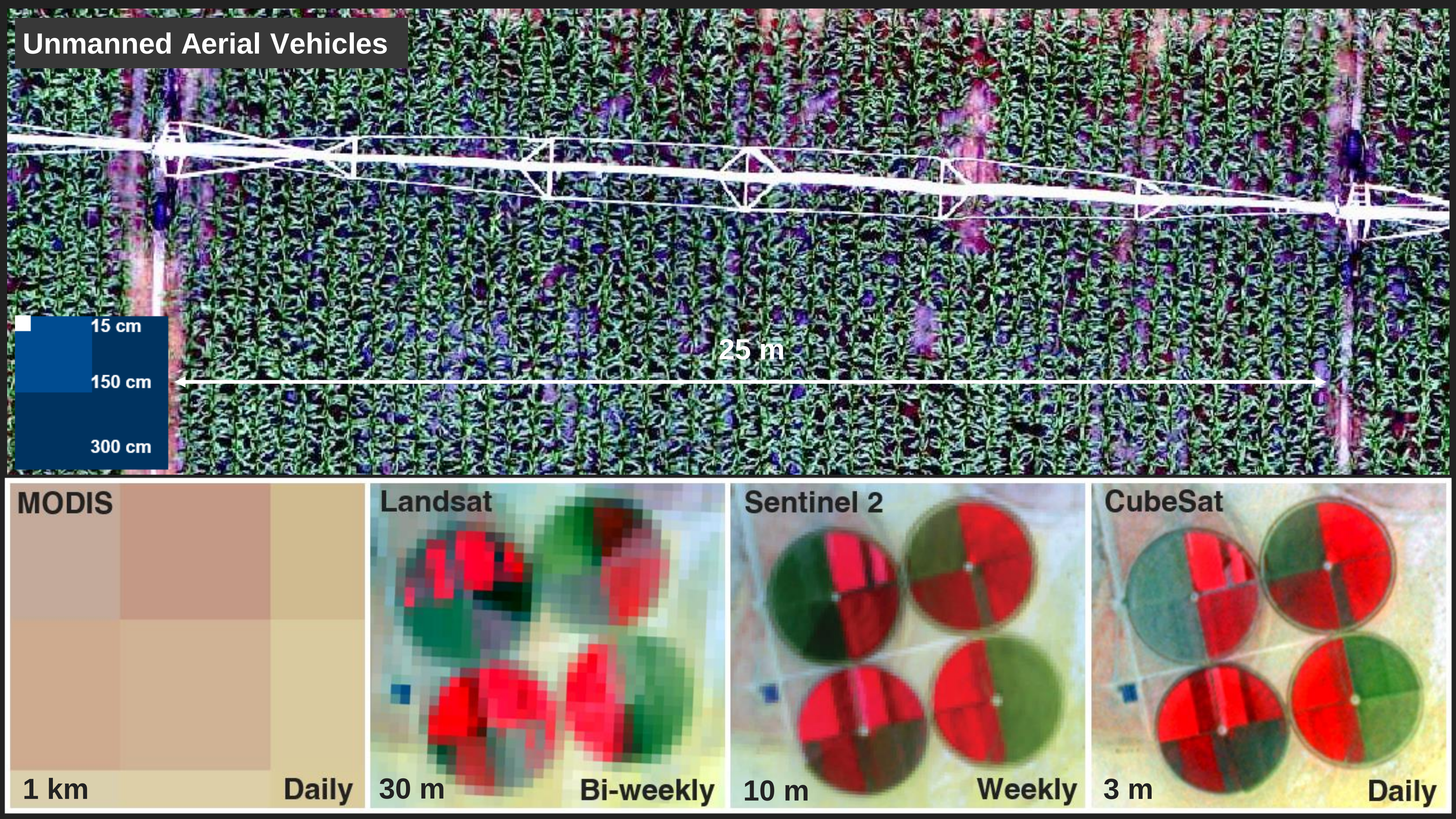
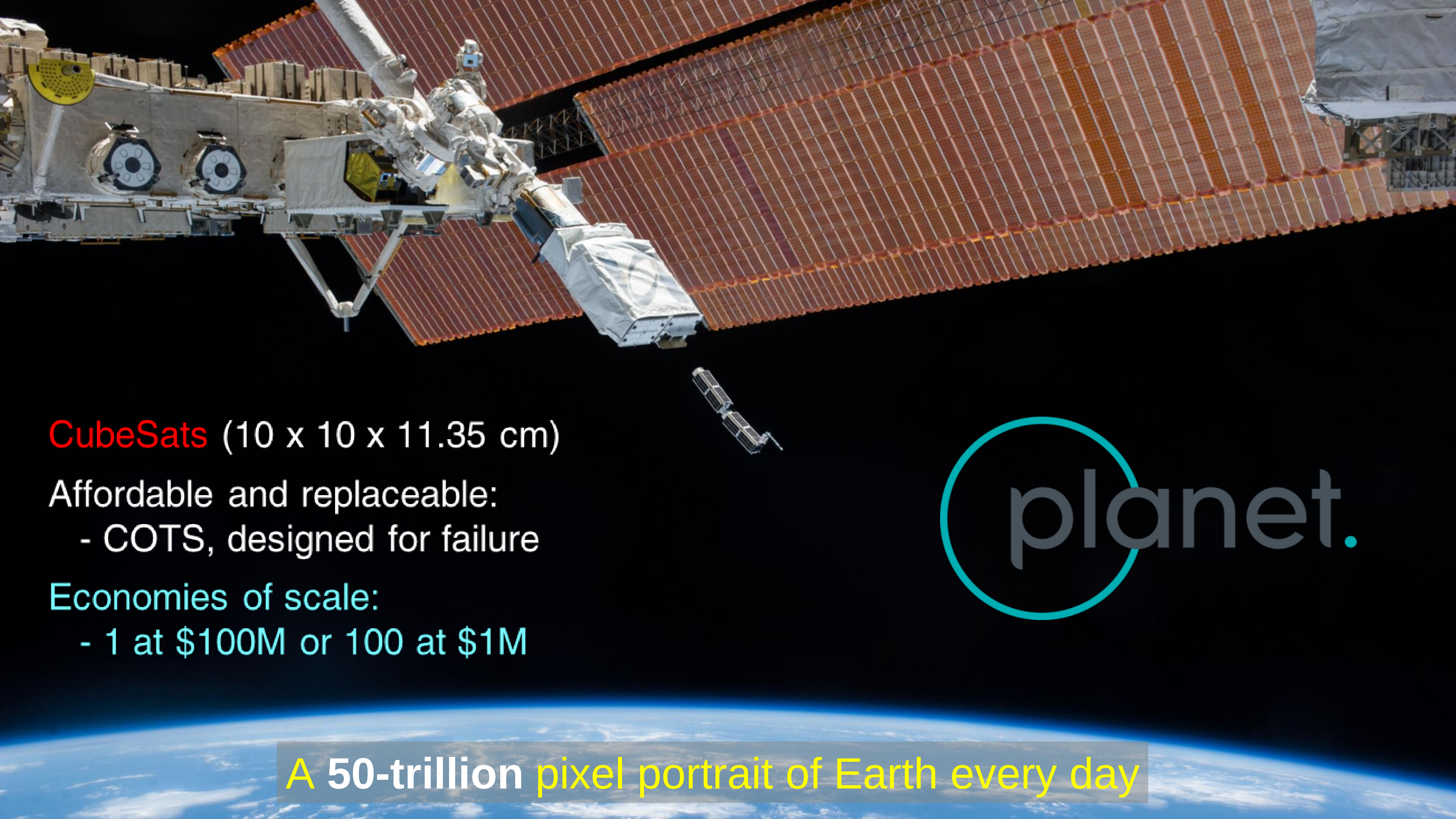
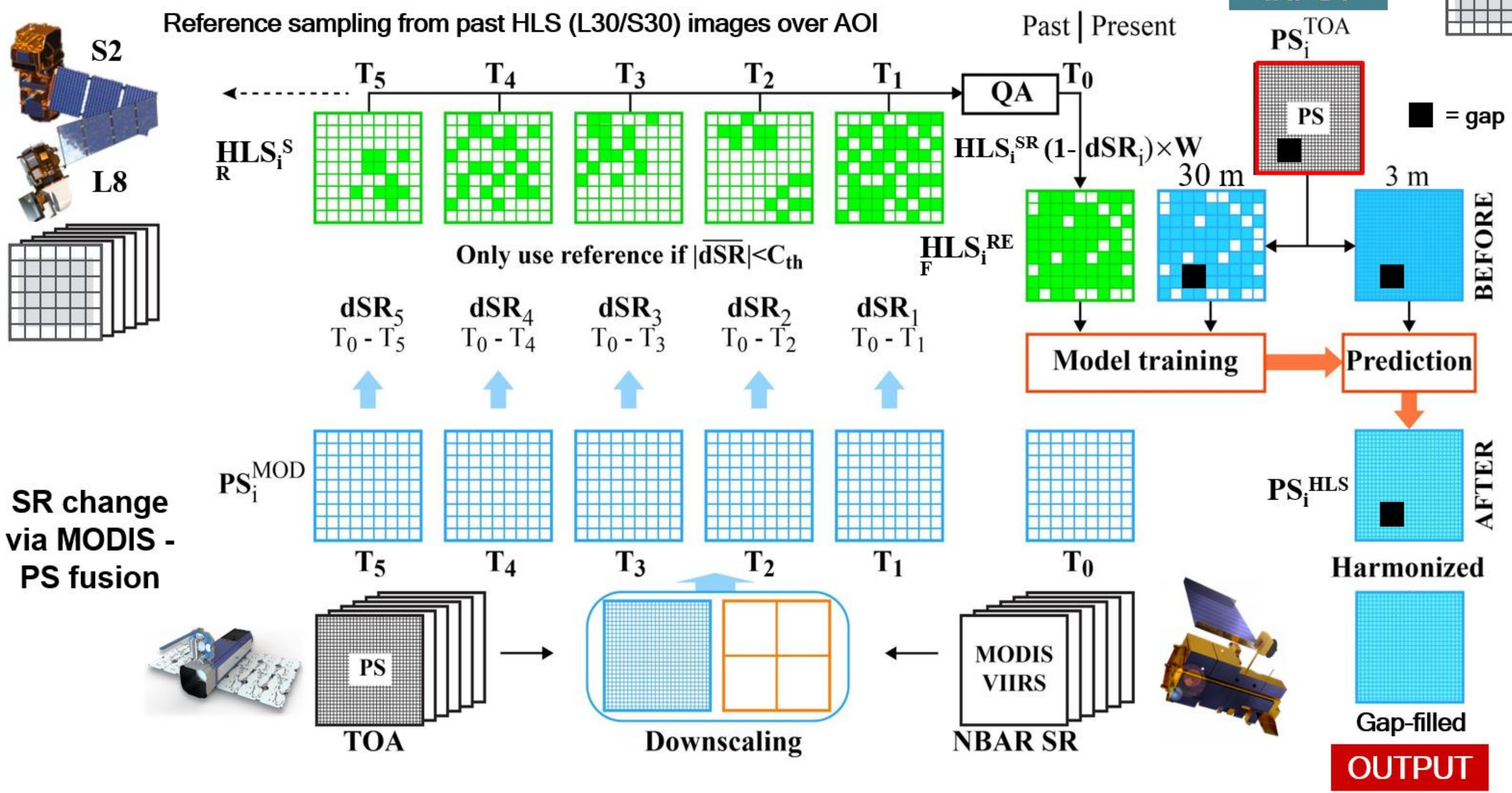
Abstract. In just the past 5 years, the field of Earth observation has progressed beyond the offerings of conventional space-agency-based platforms to include a plethora of sensing opportunities afforded by CubeSats, unmanned aerial vehicles (UAVs), and smartphone technologies that are being embraced by both for-profit companies and individual researchers. Over the previous decades, space agency efforts With these advances come new space-borne measurements, such as real-time high-definition video for tracking air pollution, storm-cell development, flood propagation, precipitation monitoring, or even for constructing digital surfaces using structure-from-motion techniques. Closer to the surface, measurements from small unmanned drones and tethered balloons have mapped snow depths, floods, and esti-


Unmanned Aerial Vehicles
15 cm
150 cm
300 cm
25 m
MODIS
1 km
Daily
Landsat
30 m
Bi-weekly
Sentinel 2
10 m
Weekly
CubeSat
3 m
Daily


CubeSats (10 x 10 x 11.35 cm)
Affordable and replaceable:
- COTS, designed for failure
Economies of scale:
- 1 at $100M or 100 at $1M
planet.
A 50-trillion pixel portrait of Earth every day

Video Courtesy of Dr Rasmus Houborg, Planet

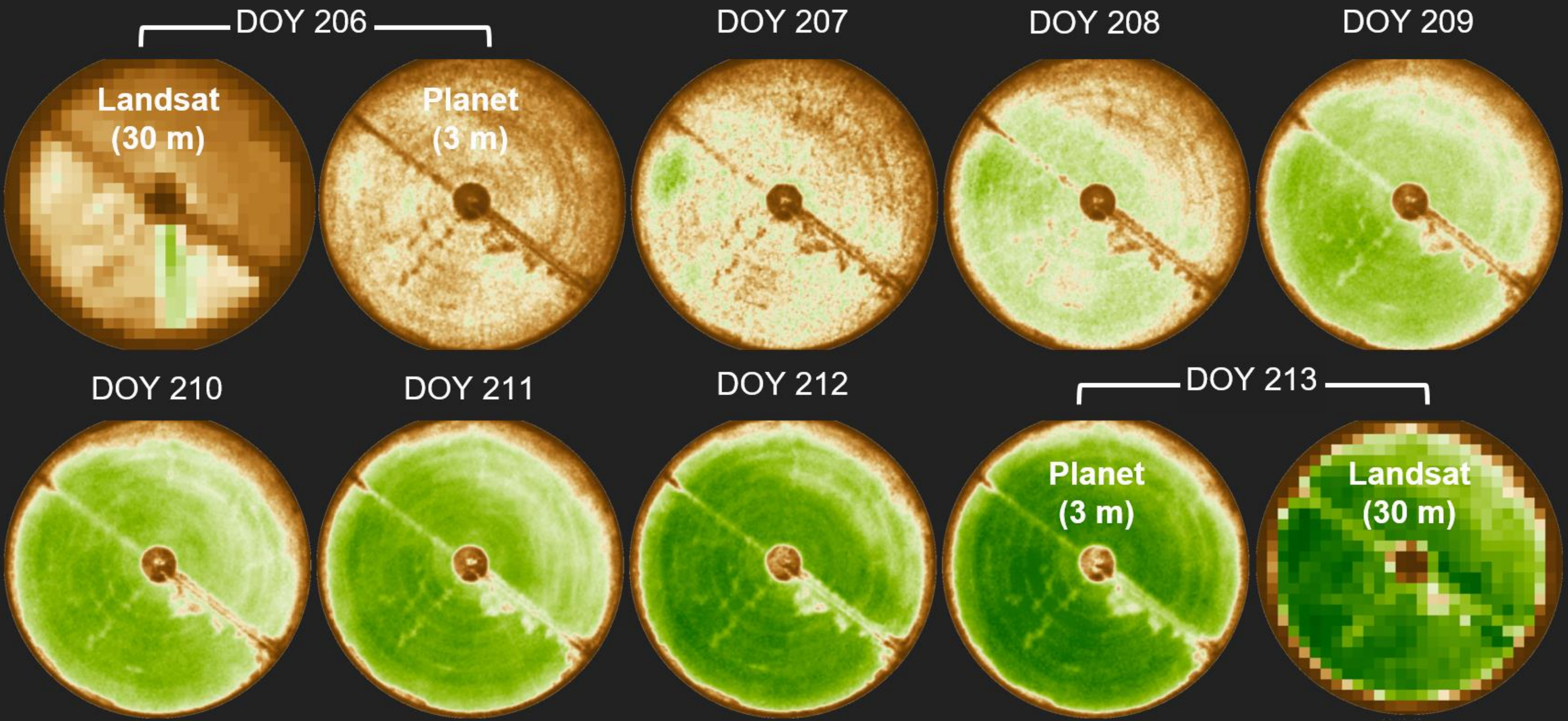
CESTEM HLS reference sampling and calibration



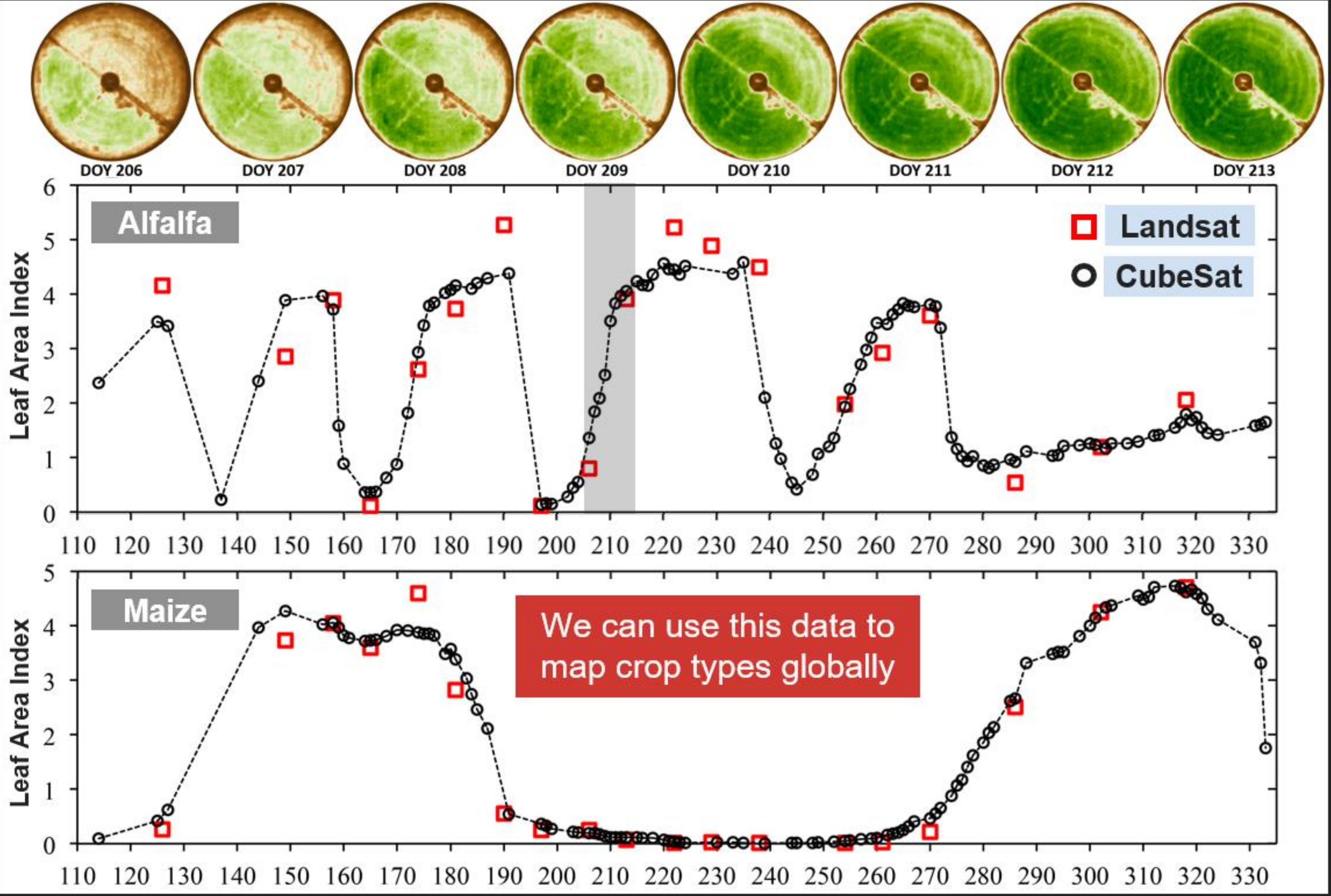
Houborg and McCabe (2018) “A CubeSat enabled spatiotemporal enhancement method utilizing Planet, Landsat and MODIS data”, RSE

Video Courtesy of Dr Rasmus Houborg, Planet

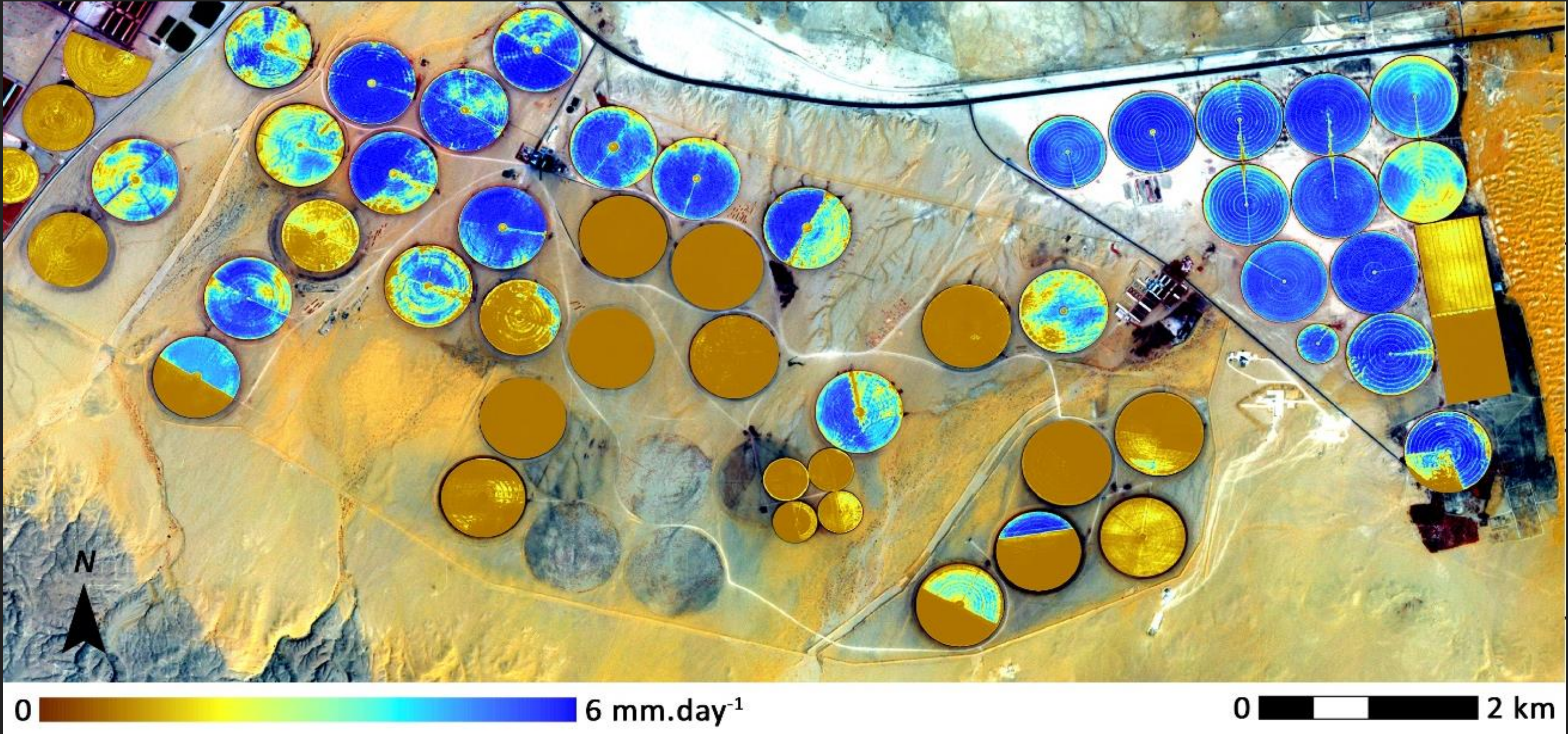
Tracking crop health and condition from space



Expand the approach to any variable (e.g. LAI). High-temporal resolution allows for discrimination of crop type and phenology



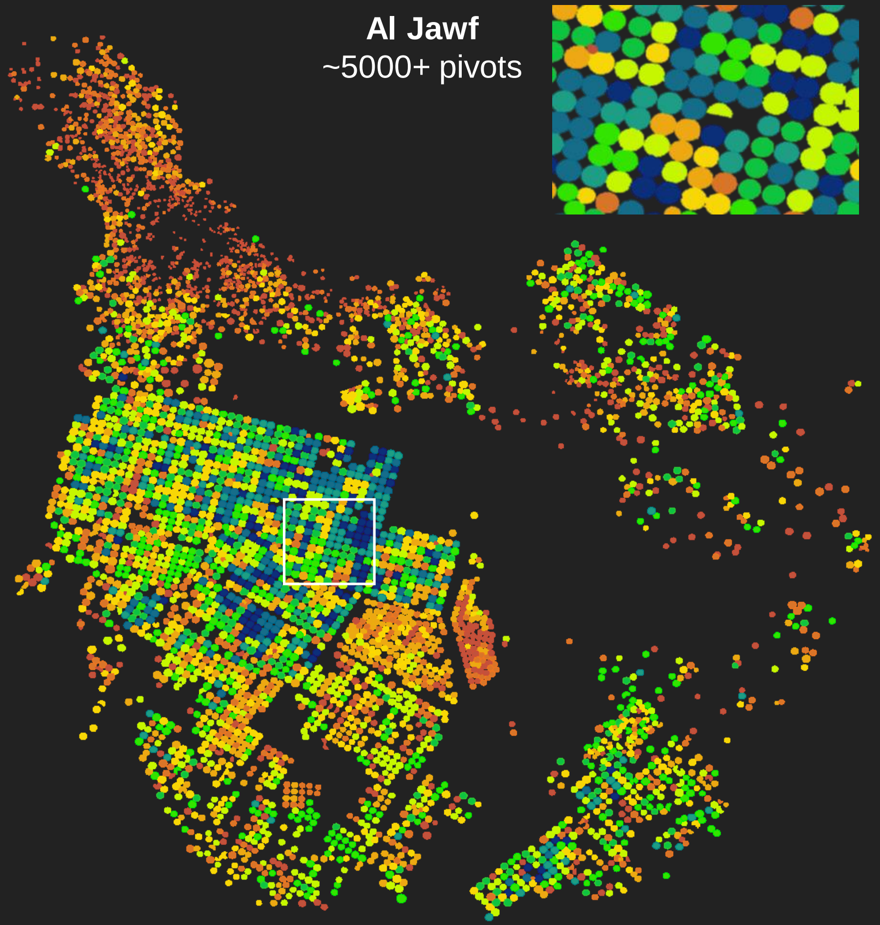
Crop-water use retrievals: highest ever resolution from space

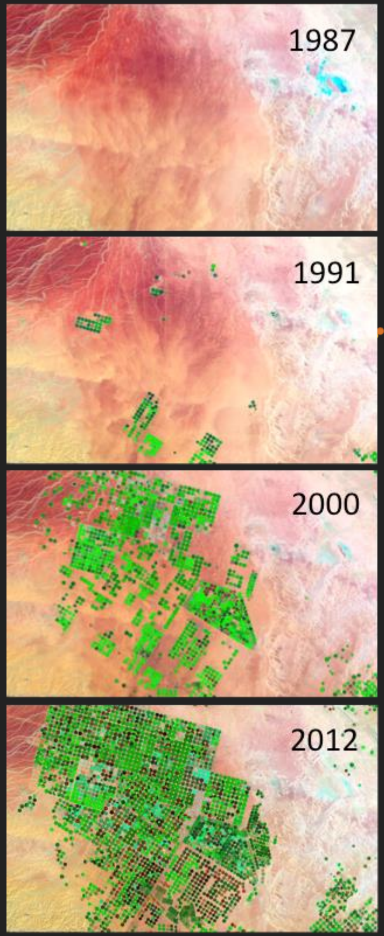


McCabe et al. (2017) "CubeSats in hydrology: ultrahigh resolution insights into vegetation dynamics and terrestrial evaporation" **Water Resources Research**

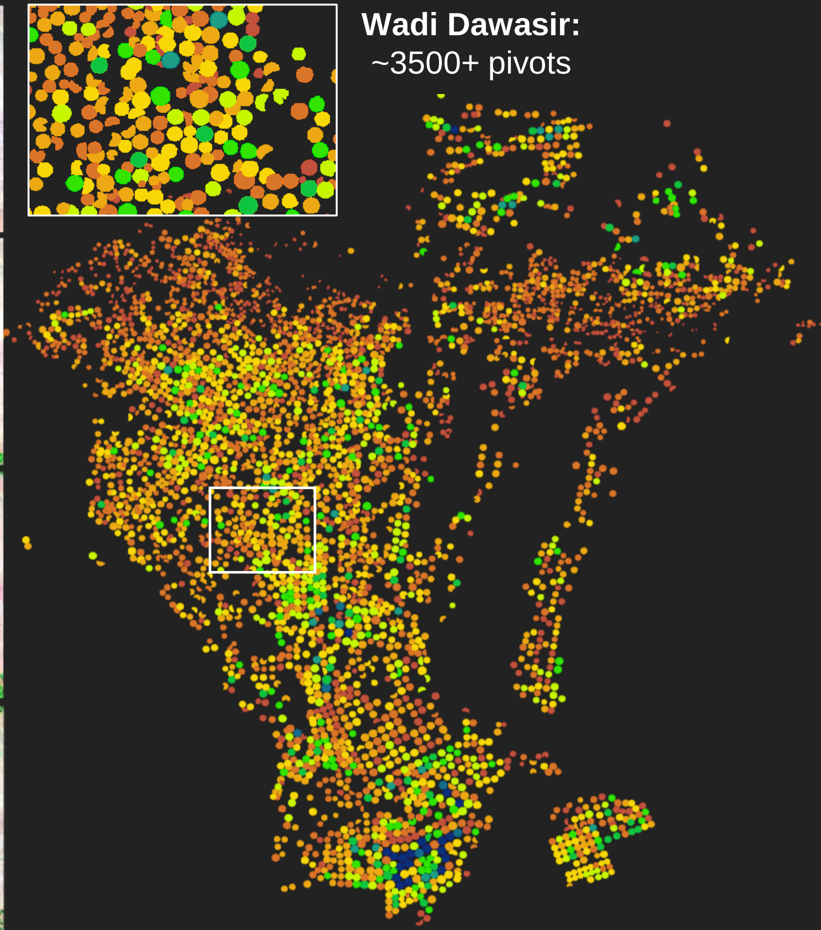
Big-data: every field, everywhere, all the time

Al Jawf
~5000+ pivots

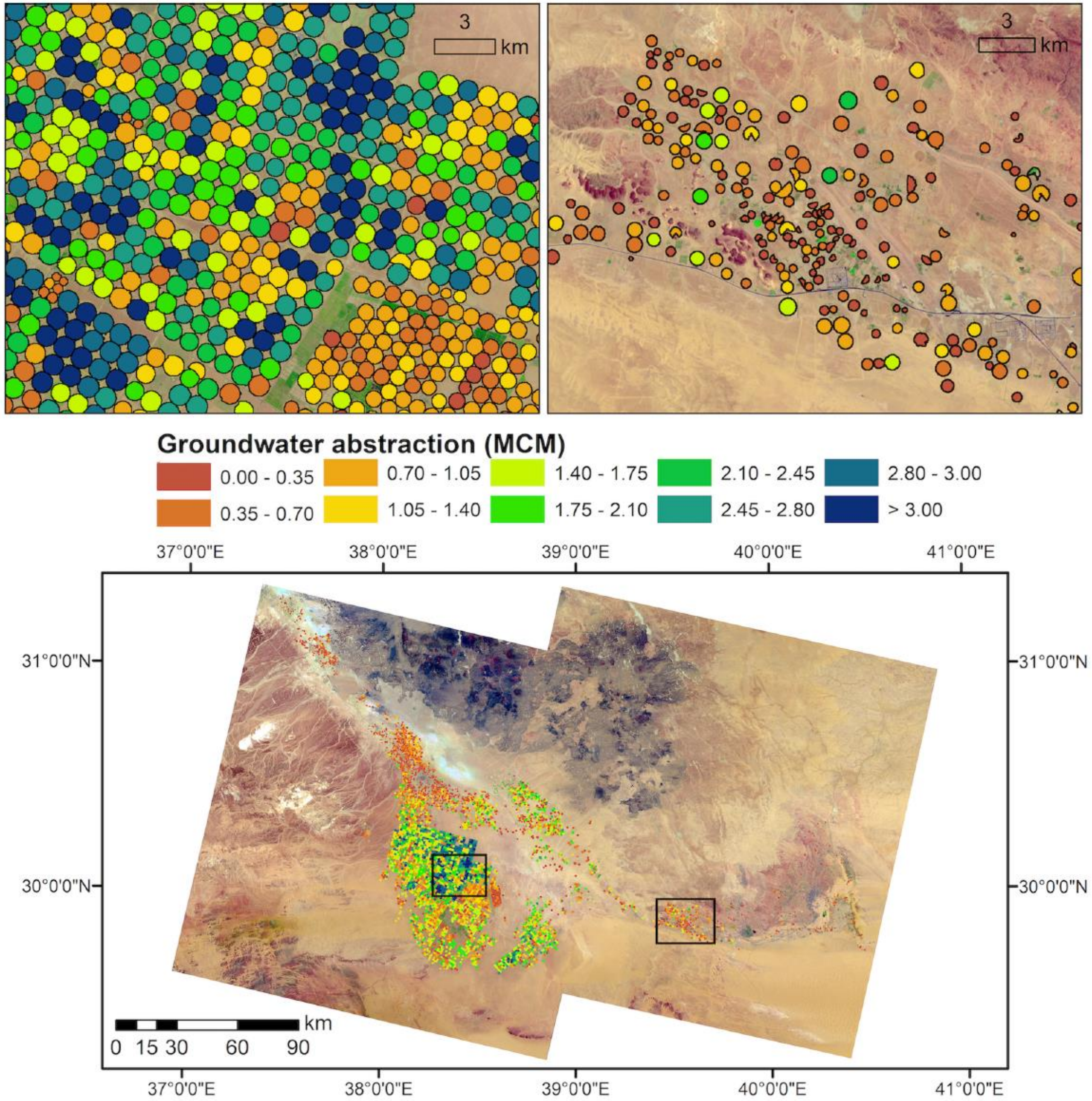




Wadi Dawasir:
~3500+ pivots



Lopez et al. (2020), “Mapping groundwater for irrigated agriculture: big data, inverse modeling and a satellite-model fusion approach “, HESS



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Hydrology and Earth System Sciences
Open Access

Mapping groundwater abstractions from irrigated agriculture: big data, inverse modeling, and a satellite–model fusion approach

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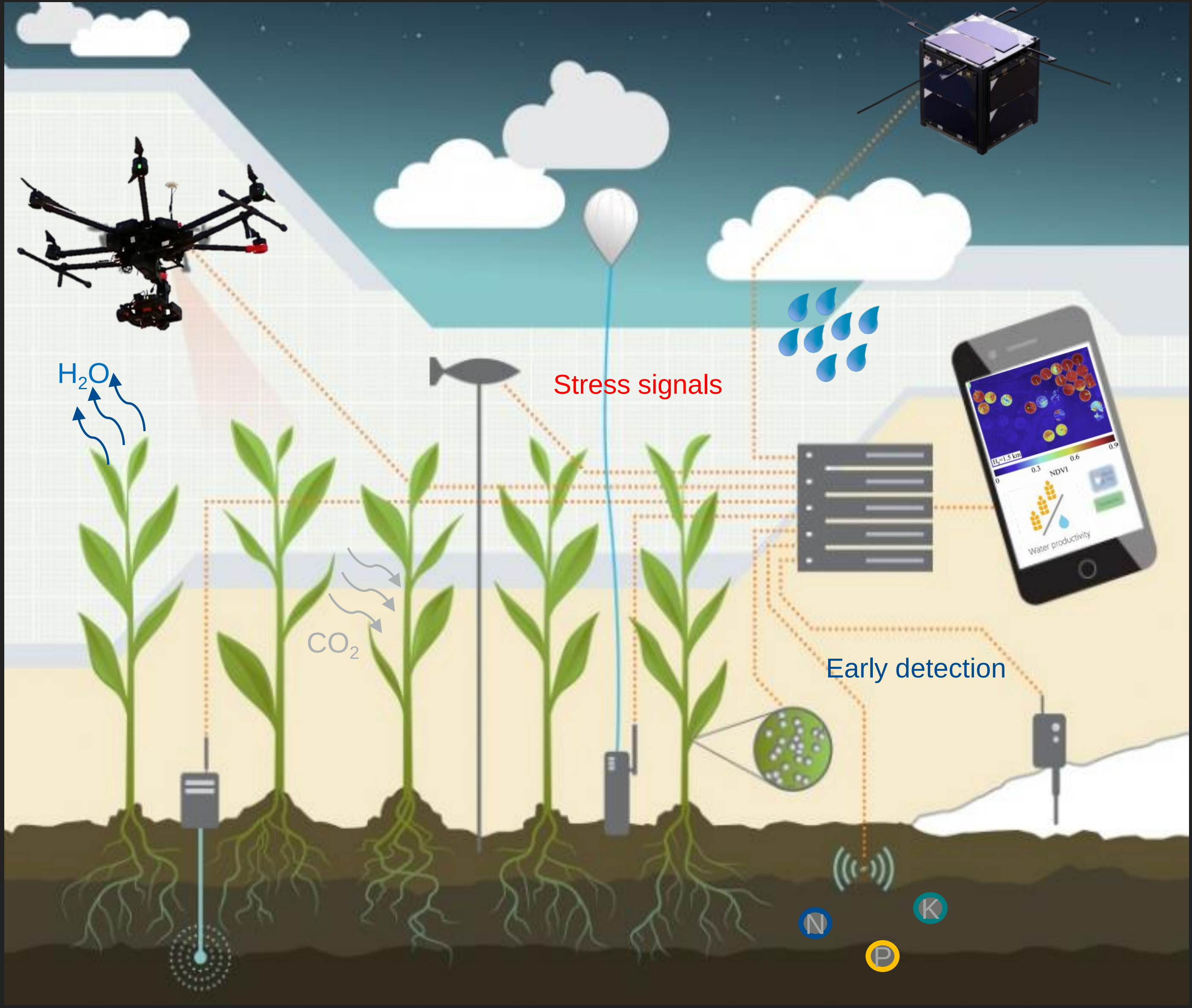
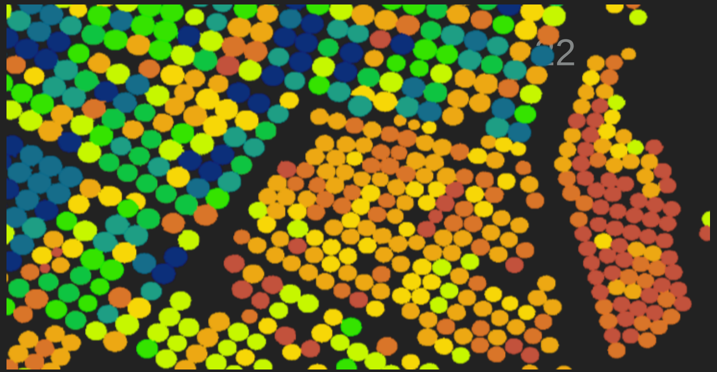
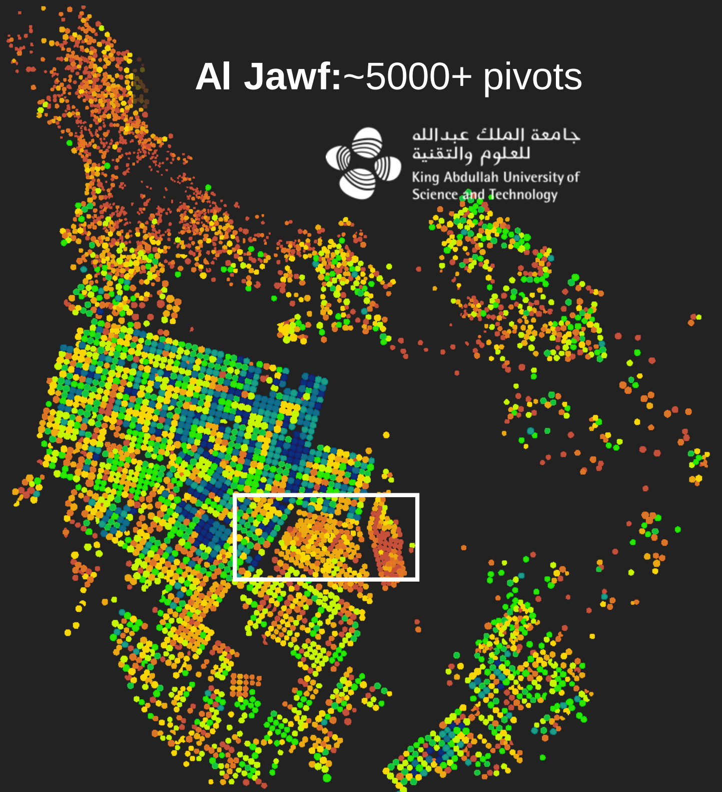
Abstract. The agricultural sector in Saudi Arabia has witnessed rapid growth in both production and area under cultivation over the last few decades. This has prompted some concern over the state and future availability of fossil groundwater resources, which have been used to drive this expansion. Large-scale studies using satellite gravimetric data show a declining trend over this region. However, water management agencies require much more detailed information on both the spatial distribution of agricultural fields and their varying levels of water exploitation through time than coarse gravimetric data can provide. Relying on self-reporting from farm operators or sporadic data collection campaigns to obtain needed information are not feasible options, nor do they allow for retrospective assessments. In this work, a water accounting framework that combines satellite data, meteorological output from weather prediction models, and a modified land surface hydrology model was developed to provide information on both irrigated crop water use and groundwater abstraction rates. Results from the local scale, comprising several thousand individual center-pivot fields, were then used to quantify the regional-scale response. To do this, a semi-automated approach for the delineation of center-pivot fields using a multi-temporal statistical analysis of Landsat 8 data was developed. Next, actual crop evaporation rates were estimated using a two-source energy balance (TSEB) model driven by leaf area index, land surface temperature, and albedo, all of which were derived from Landsat 8. The Community Atmosphere Biosphere Land Exchange (CABLE) model was then adapted to use satellite-based vegetation and related surface variables and forced with a 3 km reanalysis dataset from the Weather Research and Forecasting (WRF) model. Groundwater abstraction rates were then inferred by estimating the irrigation supplied to each individual center pivot, which was determined via an optimization approach that considered CABLE-based estimates of evaporation and TSEB-based satellite estimates. The framework was applied over two study regions in Saudi Arabia: a small-scale experimental facility of around 40 center pivots in Al Kharj that was used for an initial evaluation and a much larger agricultural region in Al Jawf province comprising more than 5000 individual fields across an area exceeding 2500 km^2. Total groundwater abstraction for the year 2015 in Al Jawf was estimated at approximately 5.5 billion cubic meters, far exceeding any recharge to the groundwater system and further highlighting the need for a comprehensive water management strategy. Overall, this novel data–model fusion approach facilitates the compilation of national-scale groundwater abstractions while also detailing field-scale information that allows both farmers and water management agencies to make informed water accounting decisions across multiple spatial and temporal scales.



H_2O
Stress signals
CO_2
Early detection
N
K
P
NDVI
Water productivity



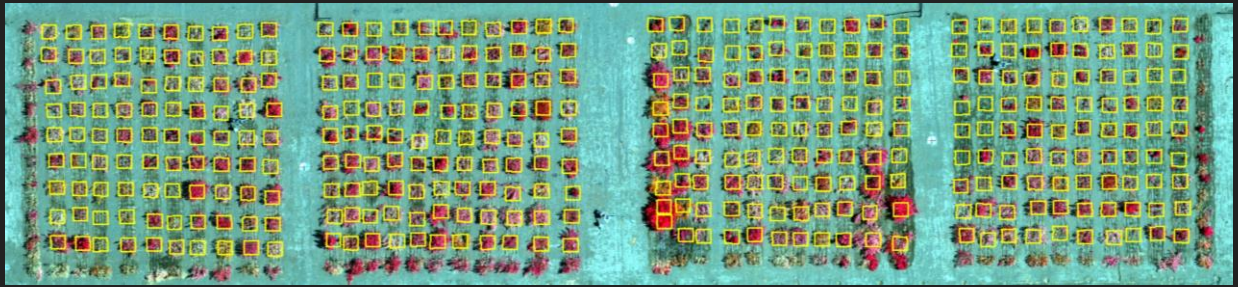


Al Jawf:~5000+ pivots
جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology

Big-data: phenotyping – from the lab to the field

Field trials can differentiate between hundreds of plant accessions

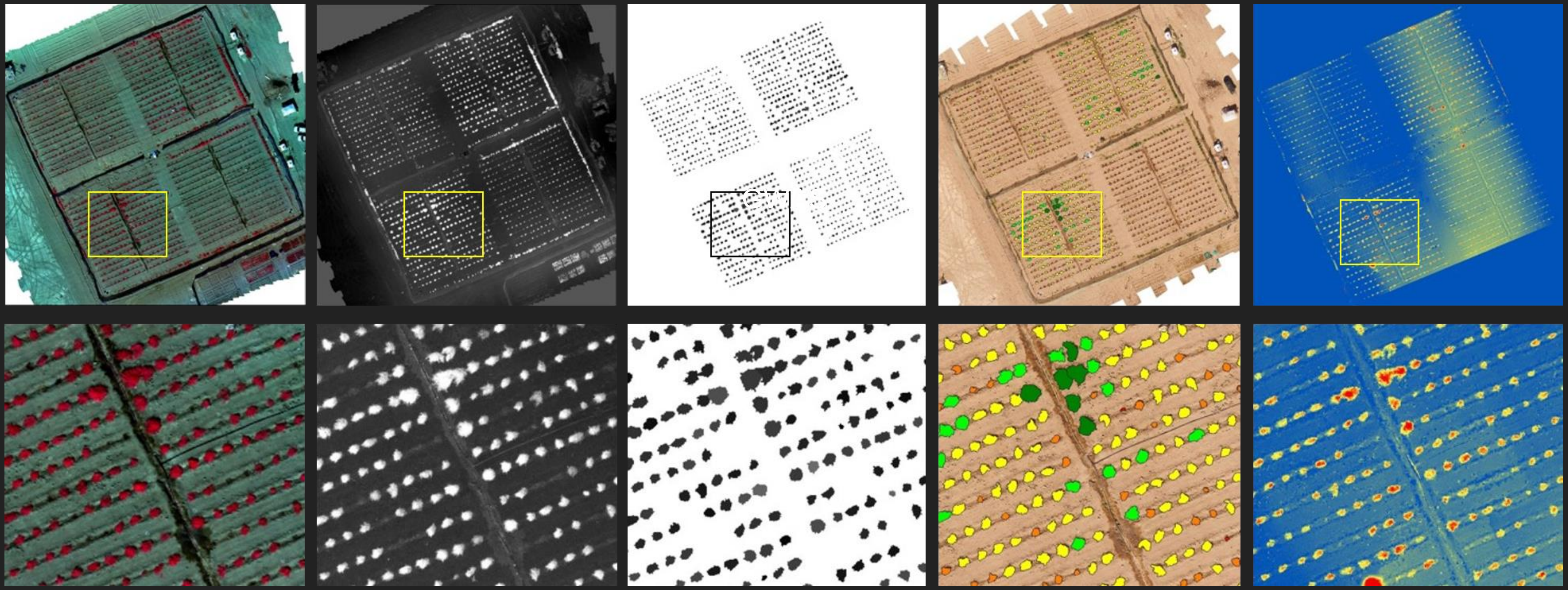
Combine hyperspectral, optical and thermal sensing with big data analytics



Johansen et al. (2019), UAV-based phenotyping using morphometric and spectral analysis can quantify responses of wild tomato…", Frontiers Plant Science

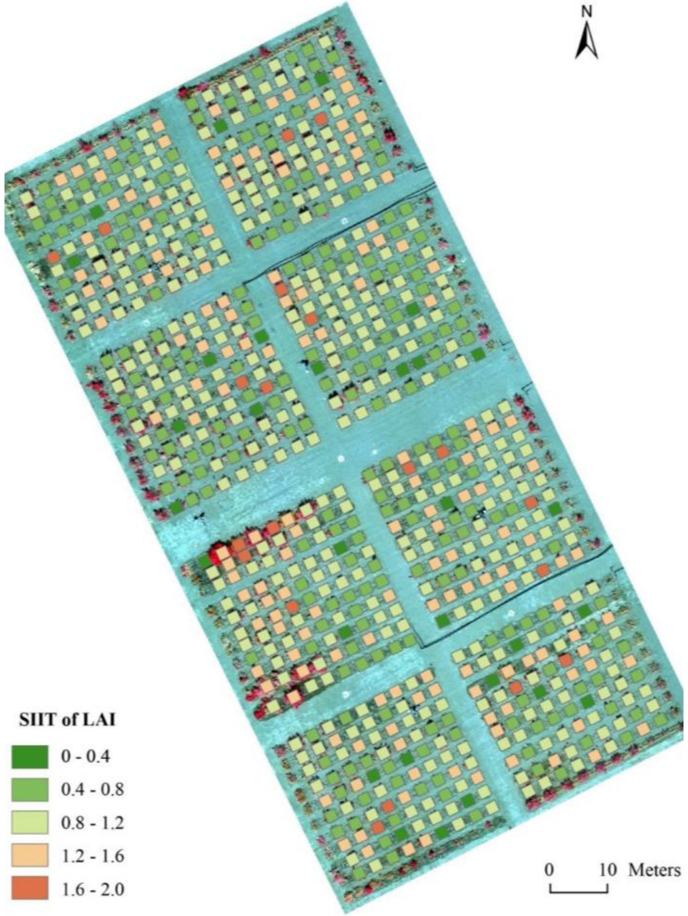
First phase is “*straightforward*”: link derived indices with observed features (yield, yield components, plant performance measurements etc.)

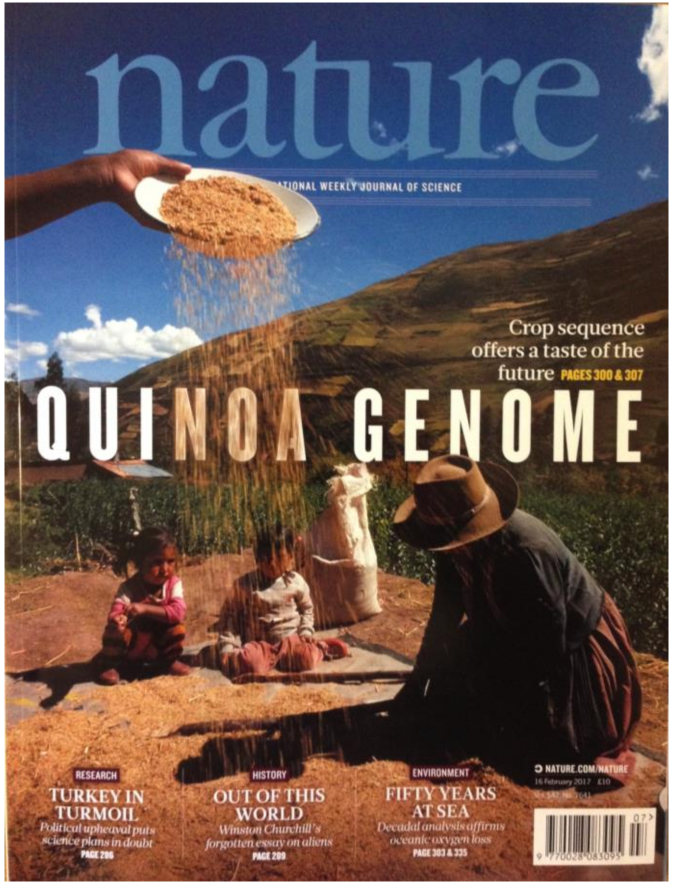
Spectral Bands | Vegetation Indices | Texture Analysis | Plant Area & Shape | Plant Height

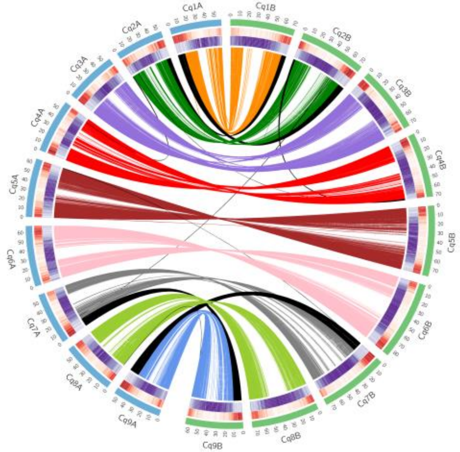


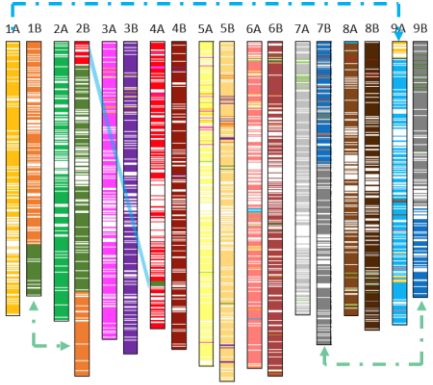
Johansen et al. (2020) “Predicting biomass and yield in a tomato phenotyping experiment using UAV imagery and random forest”, Frontiers in Artificial Intelligence

Second phase is **HARD**: requires linking the *phenotype* to the *genotype* via plant sequences, population structures, GWAS etc…all big-data!!









Slide elements courtesy of Mark Tester

Agricultural Informatics

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King Abdullah University of
Science and Technology

Thank you

Data Driven Agriculture

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