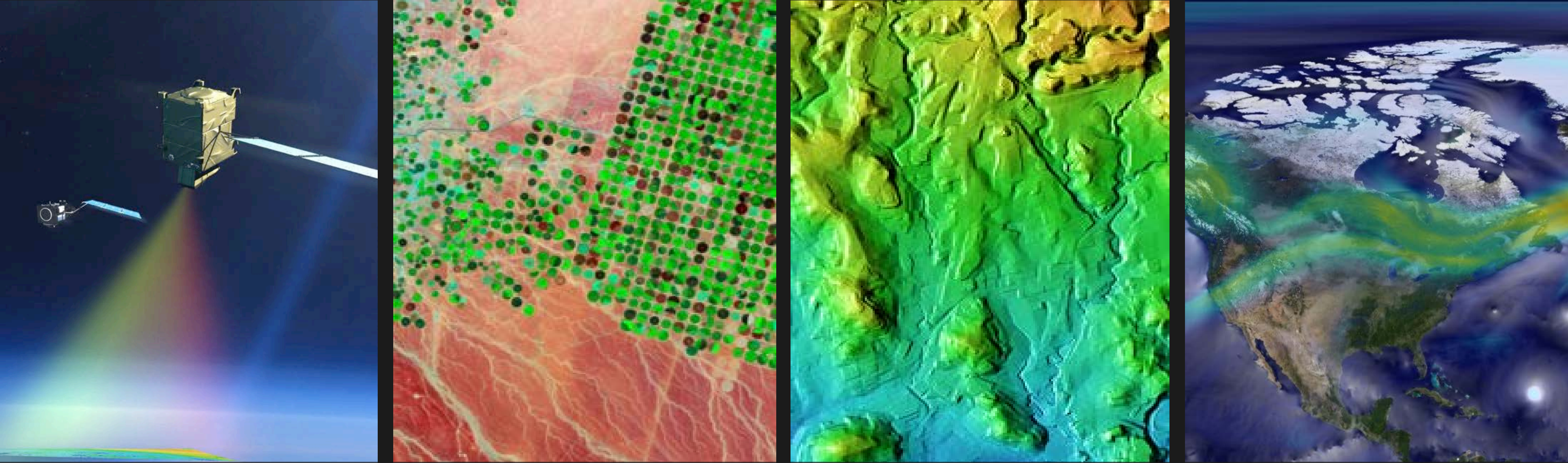

5TH ALLIANCE WEEK, GARMISCH-PARTENKIRCHEN

NOVEL SENSING PLATFORMS FOR ENHANCED EARTH OBSERVATION

PROF MATTHEW MCCABE, KAUST, SAUDI ARABIA

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2017-54, 2017
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Discussion started: 9 February 2017

Hydrology and Earth System Sciences
Discussions

The Future of Earth Observation in Hydrology

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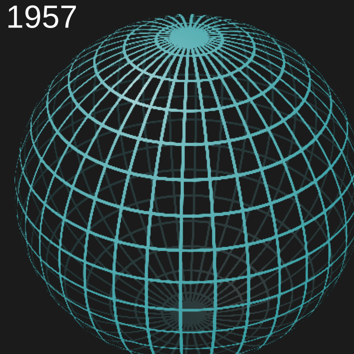
Abstract. In just the past five years, the field of Earth observation has evolved from the relatively staid approaches of government space agencies into a plethora of sensing opportunities afforded by CubeSats, Unmanned Aerial Vehicles (UAVs), and smartphone technologies that have been embraced by both for-profit companies and individual researchers. Over the previous decades, space agency efforts have brought forth well-known and immensely useful satellites such as the Landsat series and the Gravity Research and Climate Experiment (GRACE) system, with costs typically on the order of one billion dollars per satellite and with concept-to-launch timelines on the order of two decades (for new missions). More recently, the proliferation of smartphones has helped to miniaturise sensors and energy requirements, facilitating advances in the use of CubeSats that can be launched by the dozens, while providing 3-5 m resolution sensing of the Earth on a daily basis. Start-up companies that did not exist five years ago now operate more satellites in orbit than any space agency and at costs that are a mere fraction of an agency mission. With these advances come new space-borne measurements, such as high-definition video for understanding real-time cloud formation, storm development, flood propagation, precipitation tracking, or 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 estimated evaporation at sub-meter resolution, pushing back on spatio-temporal constraints and delivering new process insights. At ground level, precipitation has been measured using signal attenuation between antennae mounted on cell phone towers, while the proliferation of mobile devices has enabled citizen-science to record photos of environmental conditions, estimate daily average temperatures from battery state, and enable the measurement of other hydrologically important variables such as channel depths using commercially available wireless devices. Global internet access is being pursued via high altitude balloons, solar planes, and hundreds of planned satellite launches, providing a means to exploit the Internet of Things as a new measurement domain. Such global access will enable real-time collection of data from billions of smartphones or from remote research platforms. This future will produce petabytes of data that can only be accessed via cloud storage and will require new analytical approaches to interpret. The extent to which today's hydrologic models can usefully ingest such massive data volumes is not clear. Nor is it clear whether this deluge of data will be usefully exploited, either because the measurements are superfluous, inconsistent, not accurate enough, or simply because we lack the capacity to process and analyse them. What is apparent is that the tools and techniques afforded by this array of novel and game-changing sensing

A V-2 missile launched from the White Sands Missile Range, New Mexico USA

THE FIRST PICTURE OF EARTH TAKEN FROM SPACE, WAS PHOTOGRAPHED BY A V-2 MISSILE, 65 MILES ABOVE THE GROUND, ON OCTOBER 24, 1946.

Sputnik-1 was launched by the USSR on 4th October 1957

A 58 cm metal sphere that changed the world



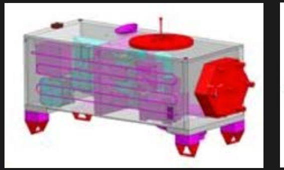
Sputnik broadcast radio pulses from space…

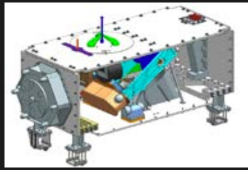
- Information on atmospheric density (from orbital drag)
- Radio propagation offered insight into the ionosphere
- Indirectly created NASA (and DARPA)

SOME NEAR FUTURE (2017-2020) AGENCY BASED MISSIONS

The International Space Station

Japanese Experimental Module on ISS


OCO-3 2018??


ECOSTRESS 2019


GEDI - 2019

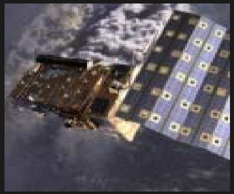
Earth Explorers

ADM-Aeolus

2018

EarthCARE

2018

Sentinel-5

2020

Sentinels

Sentinel-3B/C

2018/2020

Sentinel-4

2019

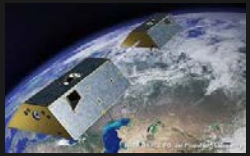
Sentinel-5P

2016

Sentinel-6

2020

NASA + Agencies

GRACE-FO

2017

JPSS-1


2017

NISAR

2020

SWOT

2020

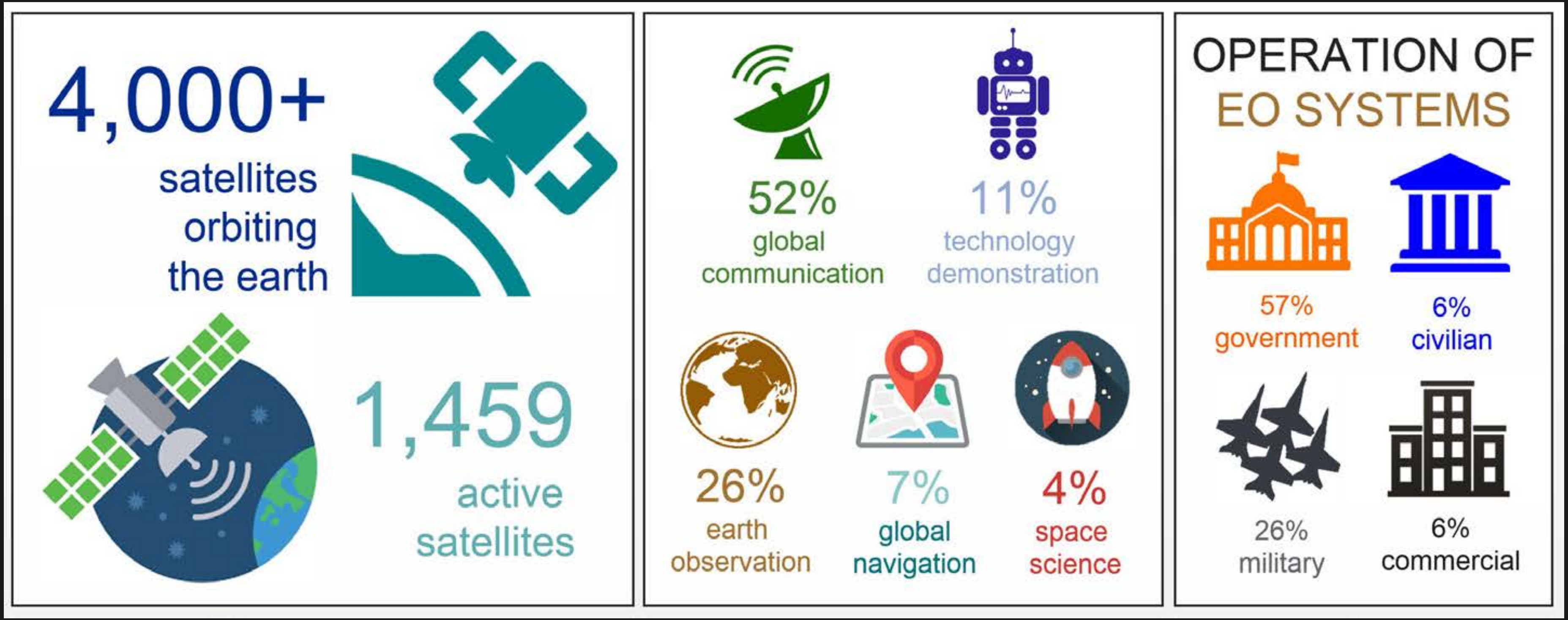
LandSat-9

2020

IS A $1B MISSION THE BEST USE OF RESOURCES

Governments and Military make up more than 80% of EO satellite systems

- Around $330 billion is spent annually (75% commercial) – can assume $10's of billions on EO
- The last few years has seen an increasing number of **Commercial and Civilian** launches



Details from http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.Vzo1eBV96t8 for 1/1/2017

DISRUPTIVE TECHNOLOGIES

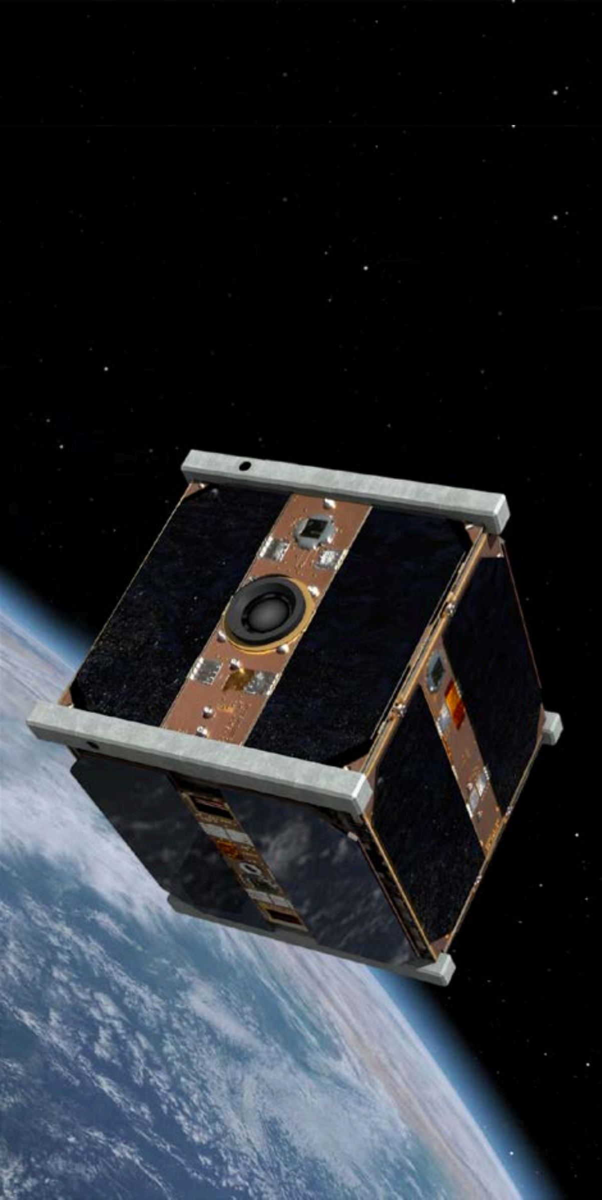
THE UBERIZATION OF EARTH OBSERVATION

"If one can figure out how to effectively reuse rockets just like airplanes, the cost of access to space will be reduced by as much as a factor of a hundred" ***Elon Musk*** *(June, 2015)*

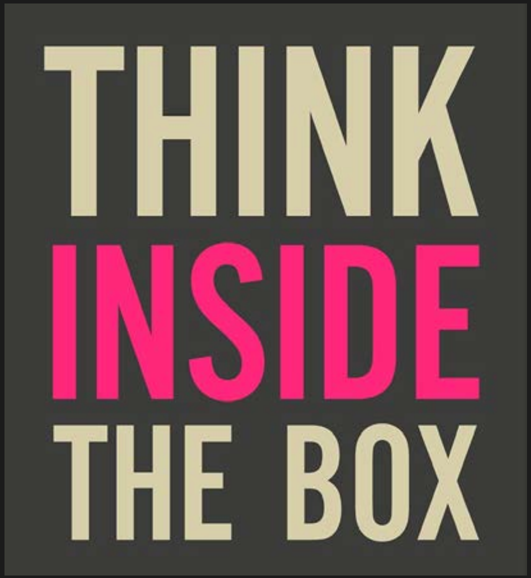
COMMERCIALIZING SPACE

Private sector is revolutionizing space, both in terms of observations and payload delivery:

- Expansion of public-private partnerships
- How can hydrological applications best piggy-back off of these efforts?
- What does this mean for non-agency based space exploration (i.e. us, the researchers?)



THE DIY SPACE AGENCY



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

4 systems due for launch in 2018 relevant to hydrology

NASA-JPL taking an exploratory role in Cubesats

- Compact Infrared Radiometer in Space (CIRiS)
- CubeSat Infrared Atmospheric Sounder (CIRAS)
- Precipitation (RainCube) + RFI sensor (CubeRRT)

planet.

- RGB (+NIR) at 3-4m GSD
- LEO (300-500km) with limited life-span
- Approaching daily repeat rate
- 13 re-builds in less than 3 years
- 130+ 3U cubesats currently in orbit
- World's largest constellation of EO satellites

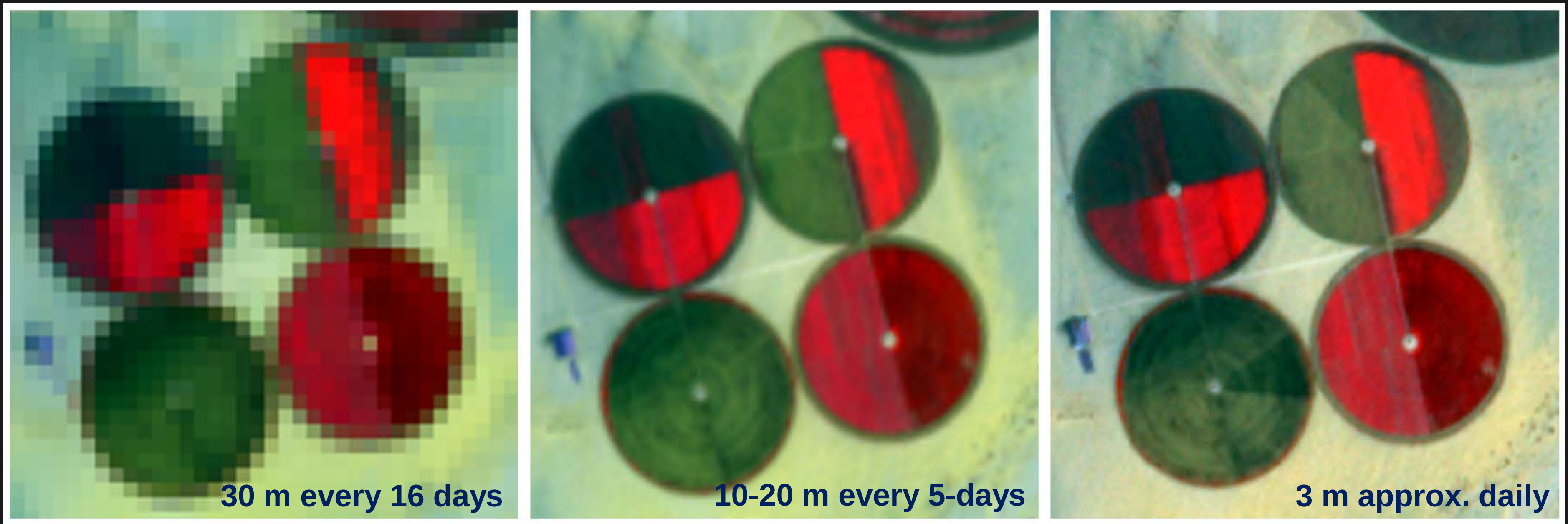
RECENTLY LAUNCHED 88 DOVES IN FEBRUARY 2017... THE FASTEST PRODUCTION AND LARGEST LAUNCH OF SATELLITES IN HISTORY!

A **50-trillion** pixel portrait of Earth every day

INFERRING VEGETATION HEALTH AND CONDITION

Using government and commercial satellites in agricultural and water resource assessm

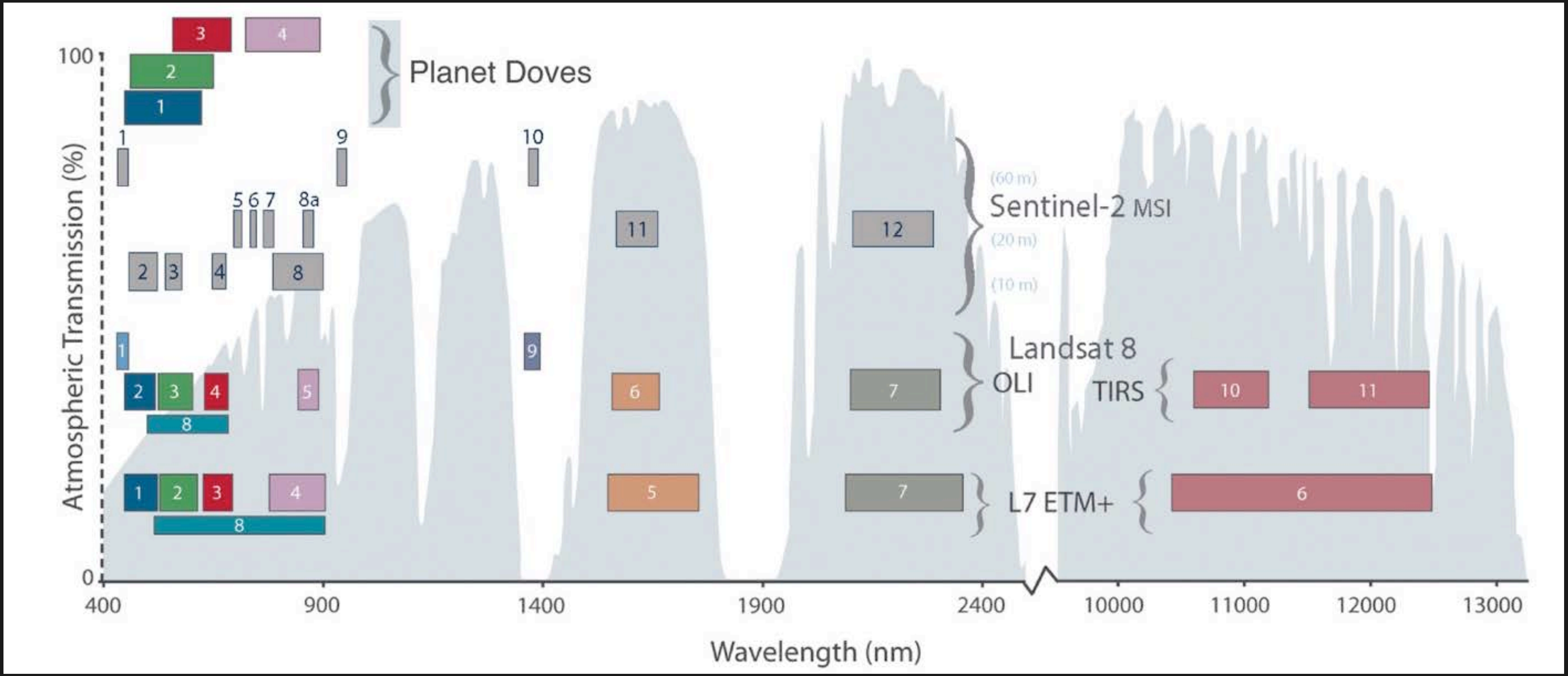
Integrating sensors to increase useable information.



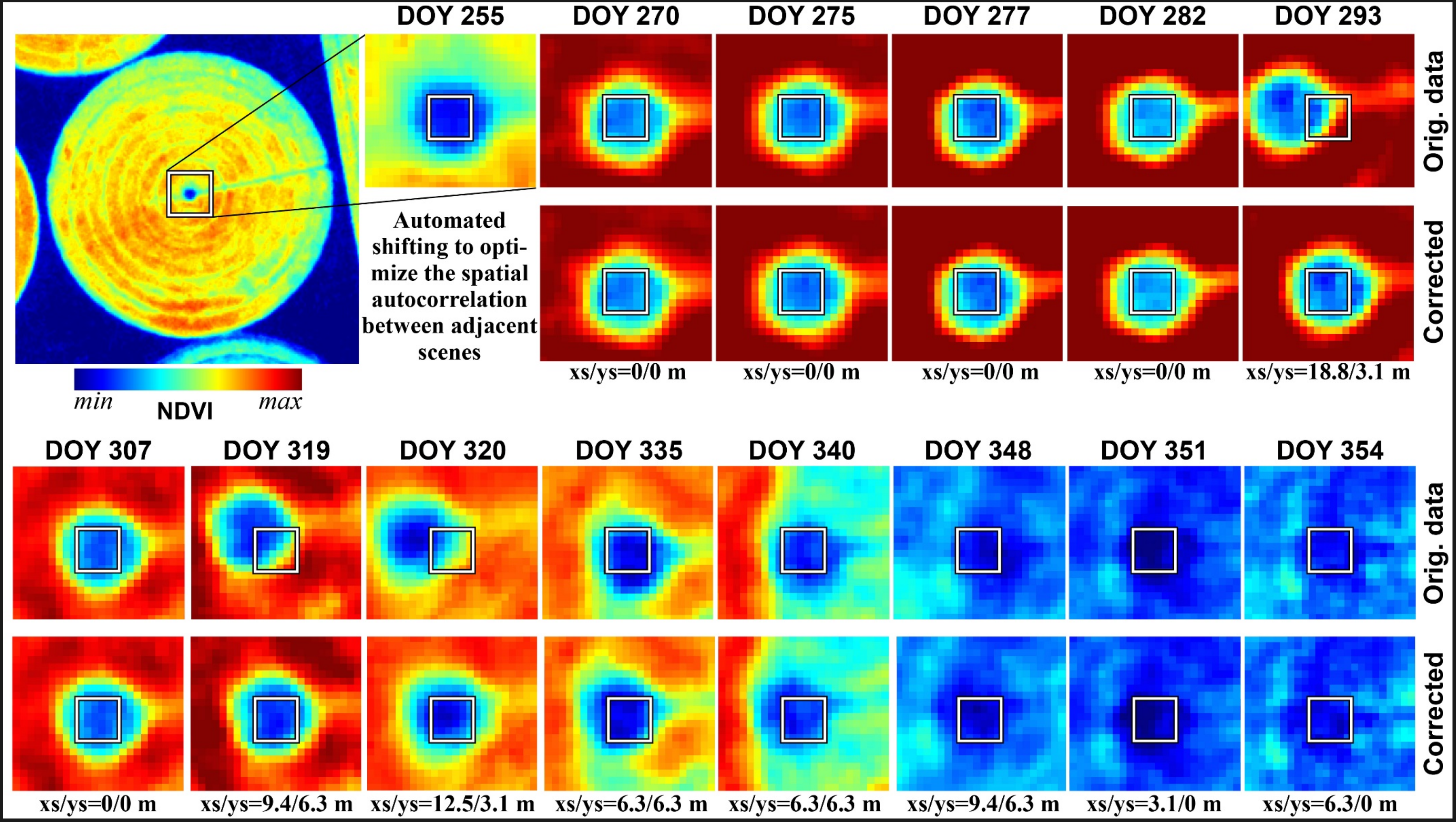
borg and McCabe (2016) "High-resolution NDVI from Planet's constellation of earth observing nano-satellites", *Rem. Sens., 8(9)*

HIGH SPATIO-TEMPORAL RESOLUTION INSIGHTS

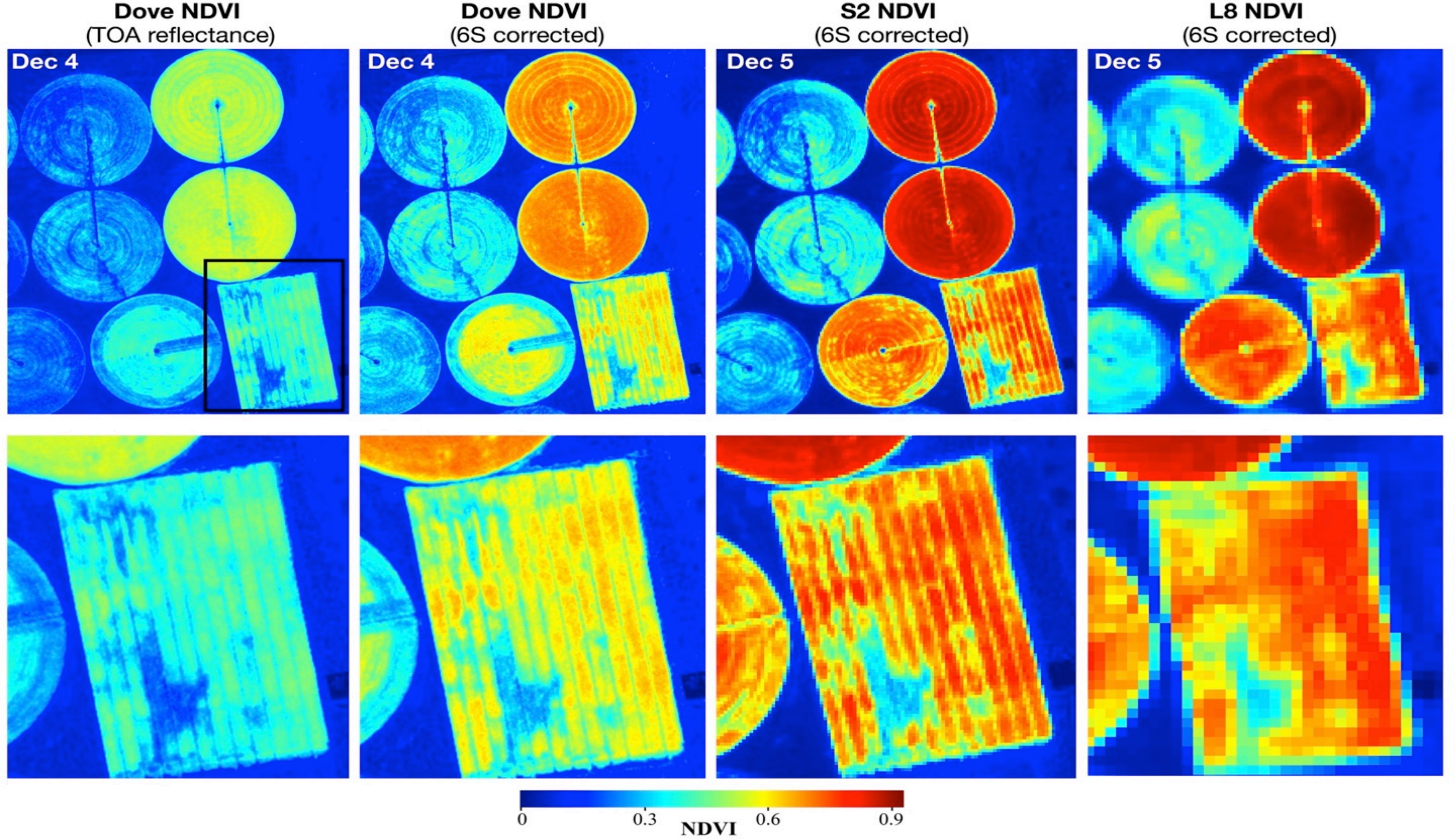
- What challenges do we need to overcome in using such data?
- How can we best use these new data for enhanced earth observation?



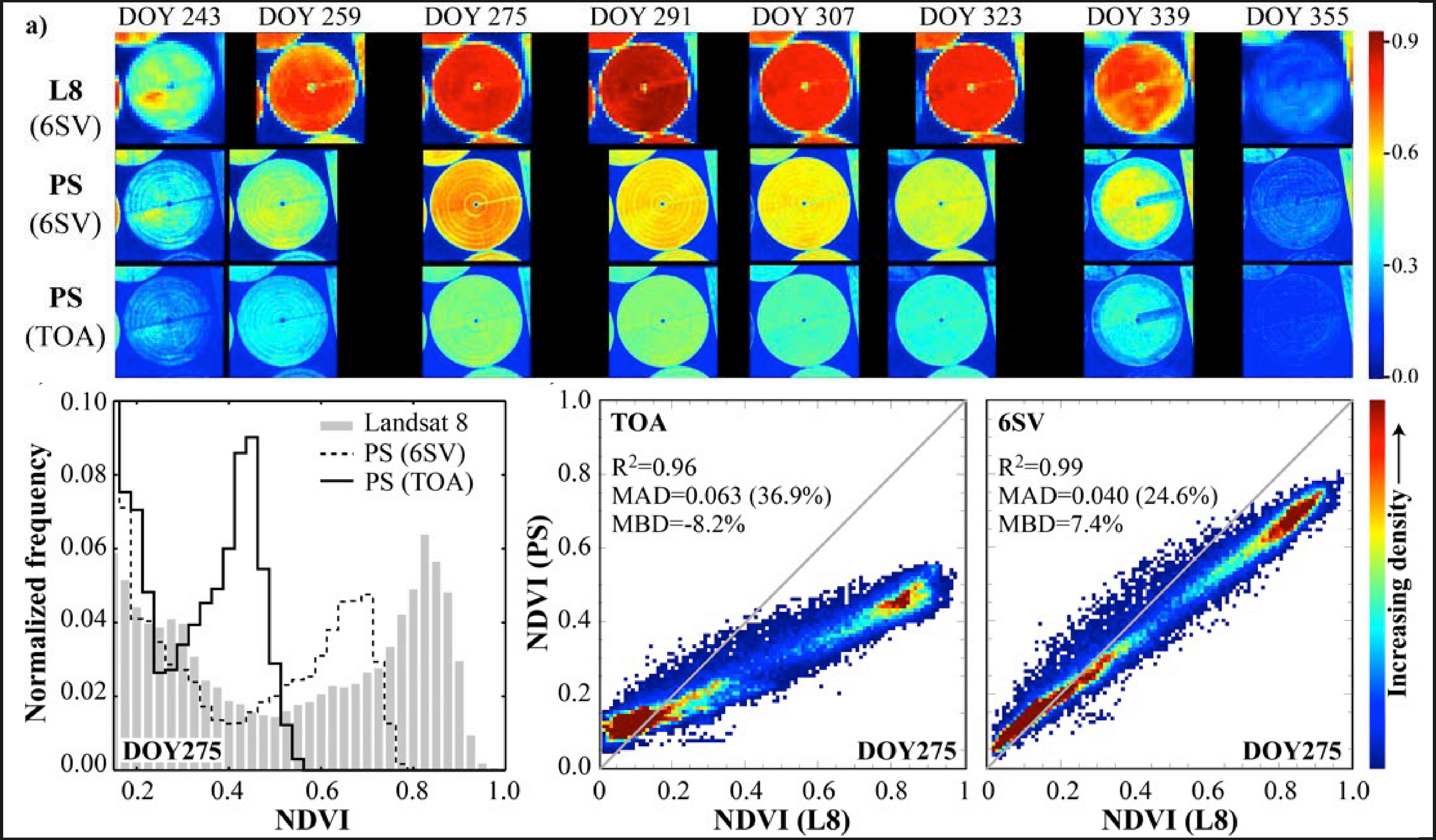
DATA CHALLENGES AND OPPORTUNITES – GEOMETRIC CORRECTIONS



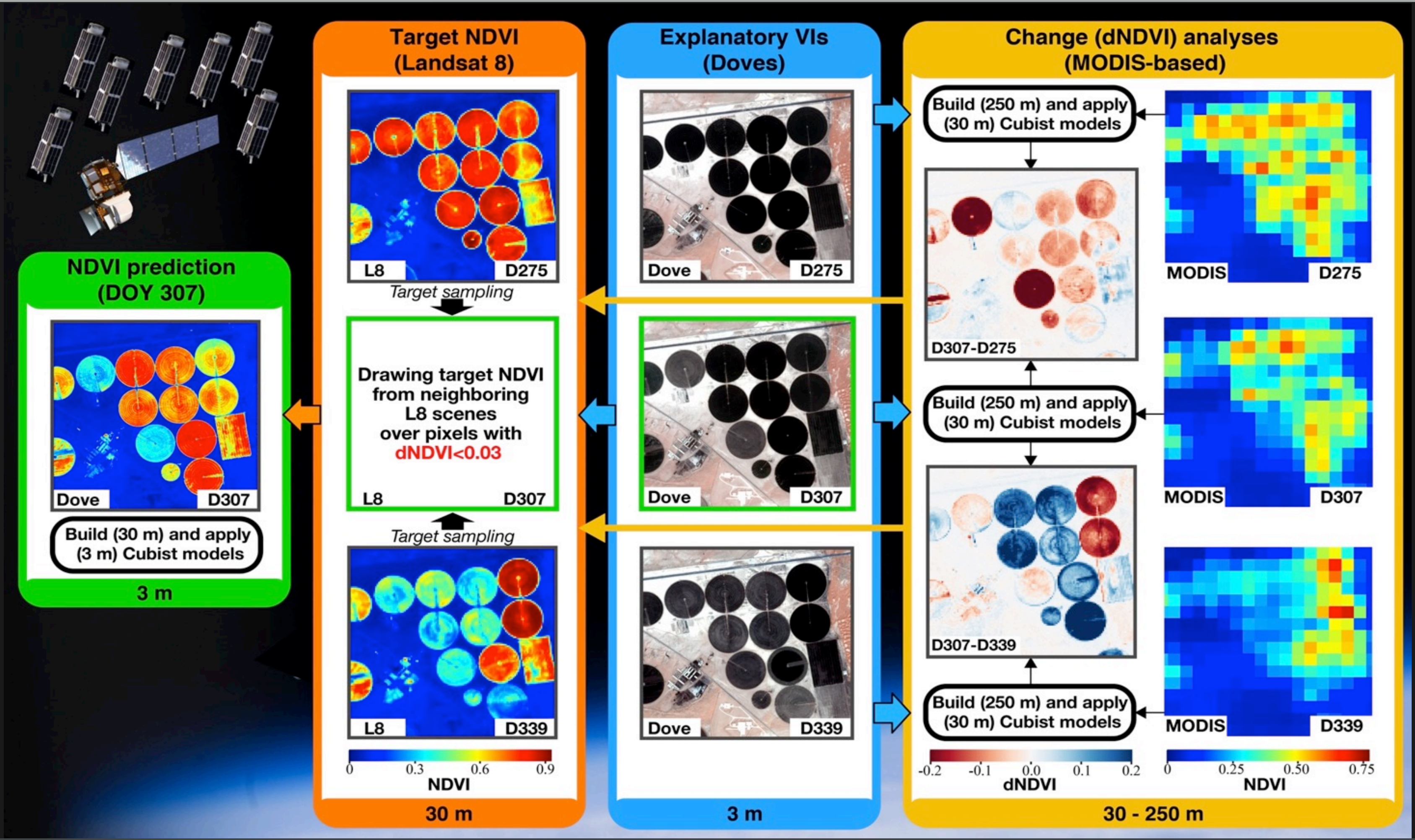
DATA CHALLENGES AND OPPORTUNITES – UNCALIBRATED REFLECTANCE DATA



DATA CHALLENGES AND OPPORTUNITES – UNCALIBRATED REFLECTANCE DATA

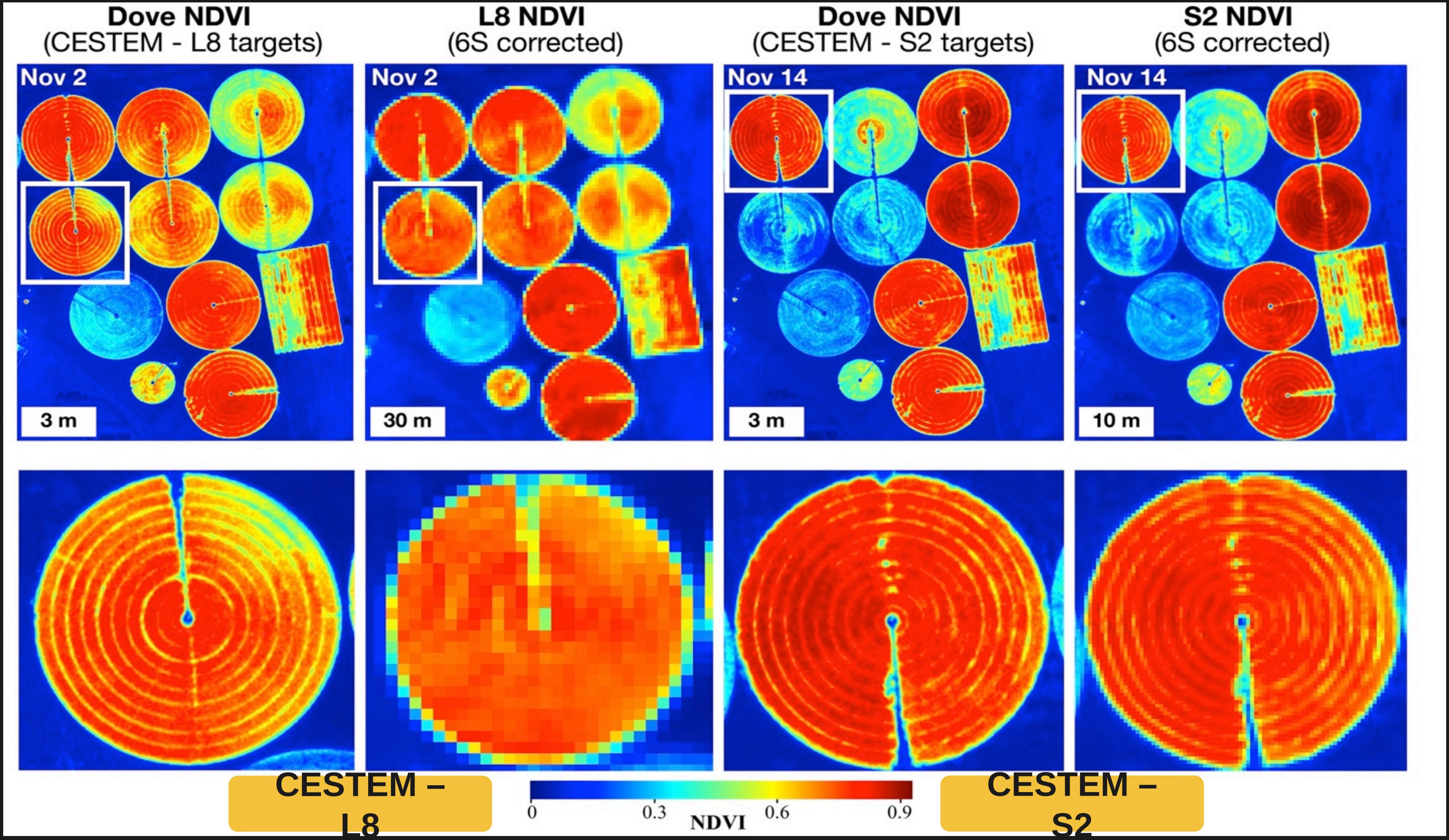


A CUBESAT ENABLE SPATIO-TEMPORAL ENHANCEMENT METHOD (CESTEM)



Houborg and McCabe (2016) "A Spatio-Temporal Enhancement Method for medium resolution LAI", *Int J Appl Earth Obs Ge*

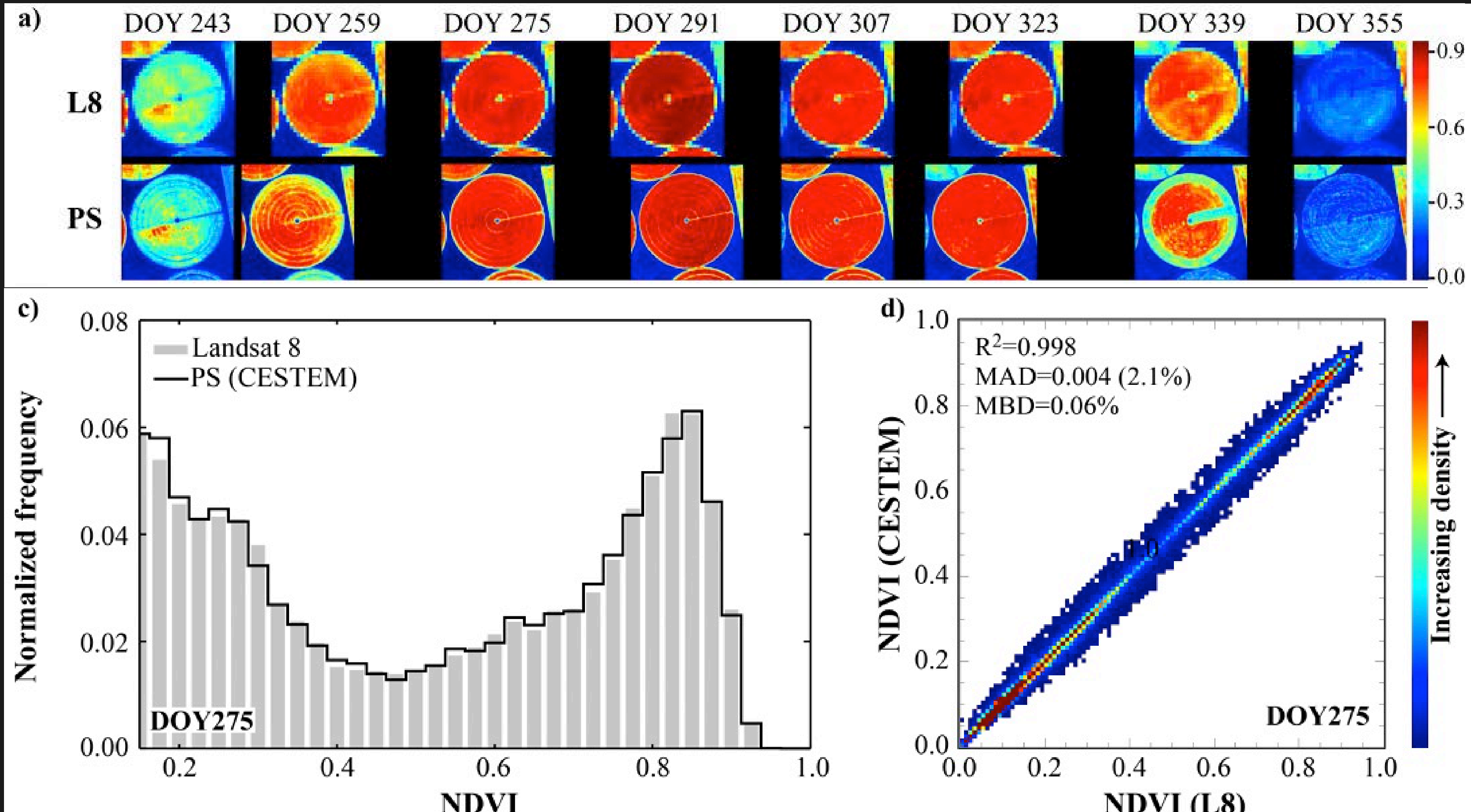
A CUBESAT ENABLE SPATIO-TEMPORAL ENHANCEMENT METHOD (CESTEM)



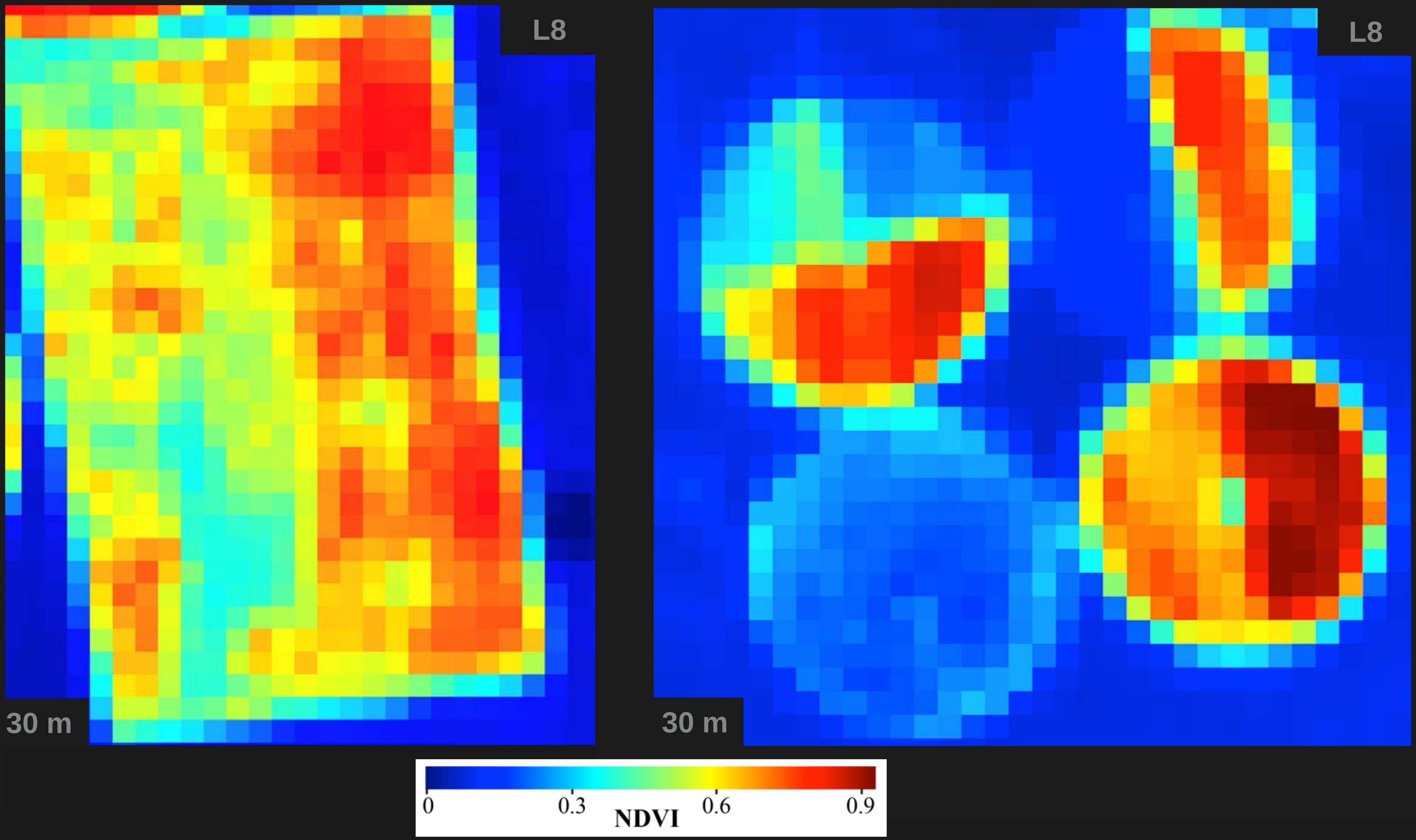
CESTEM – L8

CESTEM – S2

A CUBESAT ENABLE SPATIO-TEMPORAL ENHANCEMENT METHOD (CESTEM)



ENHANCED EARTH OBSERVATION FROM CUBESATS – RESOLUTION IMPROVEMENTS



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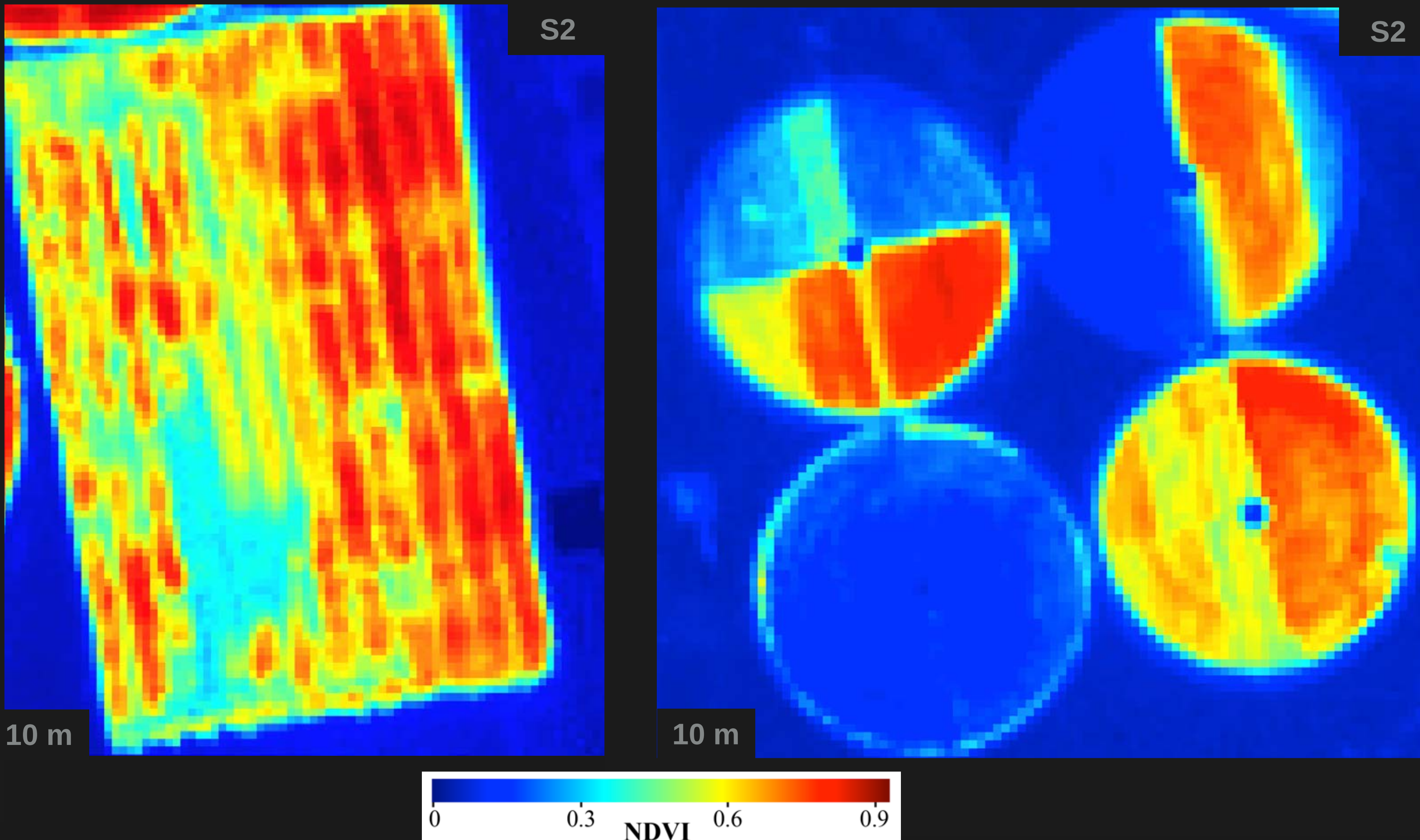
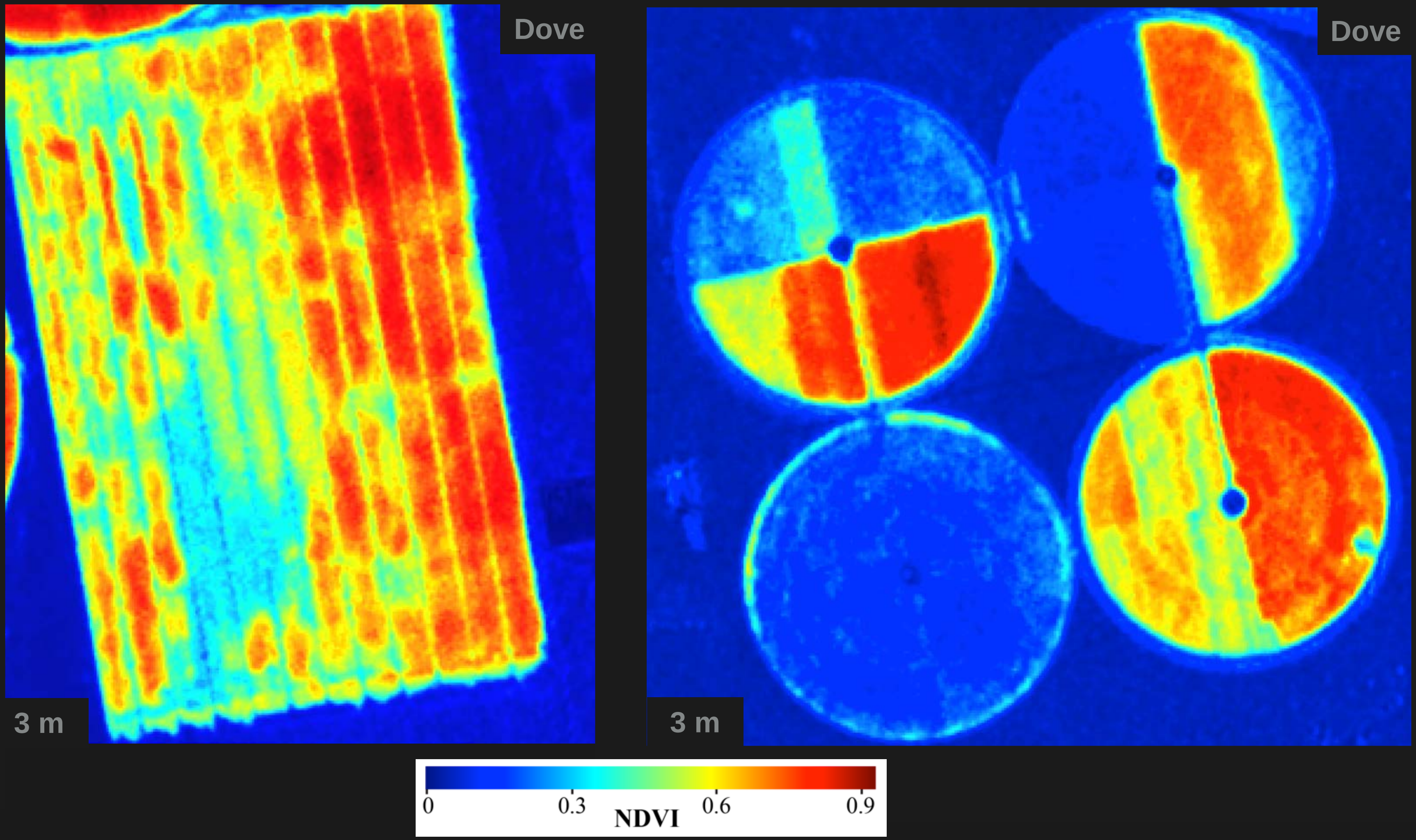
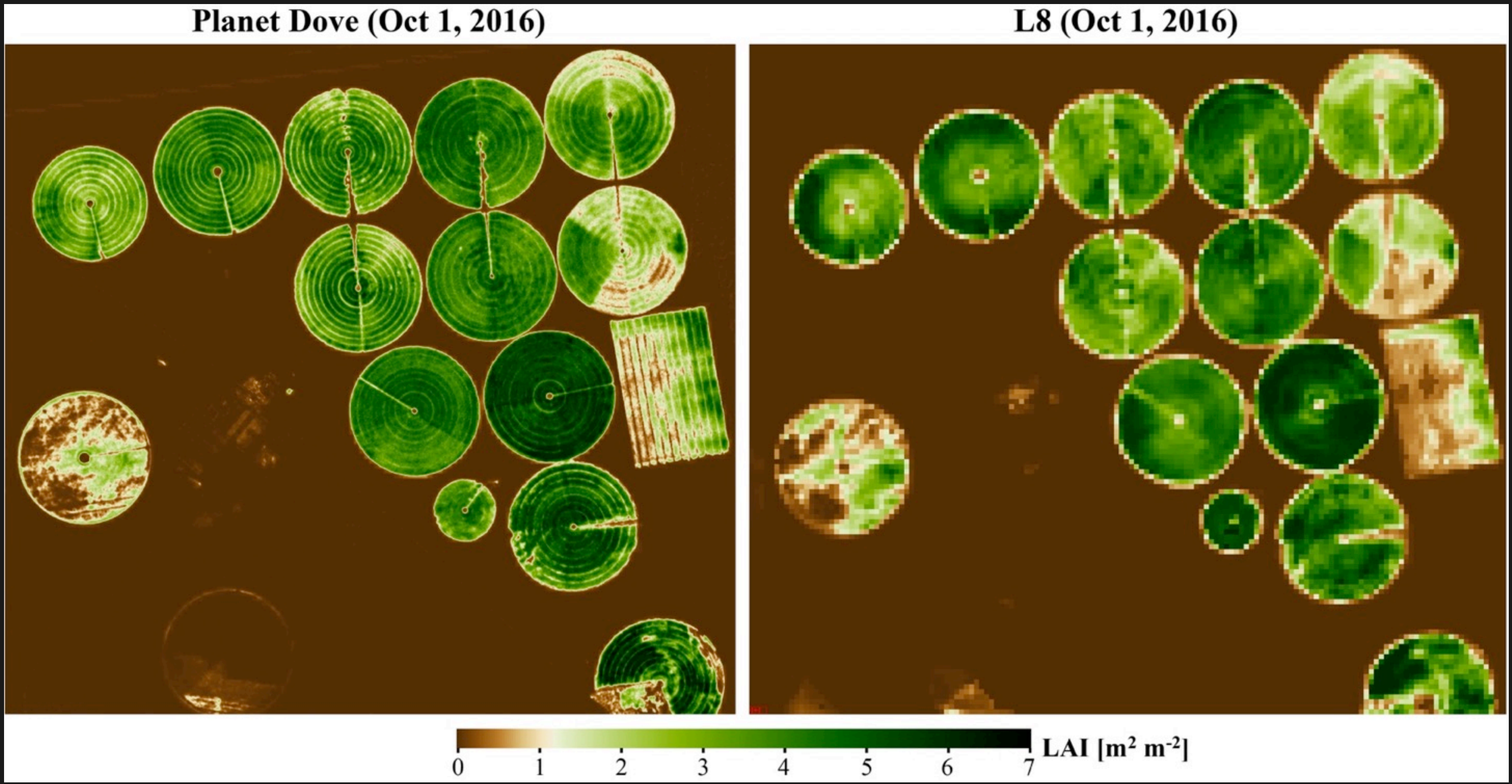


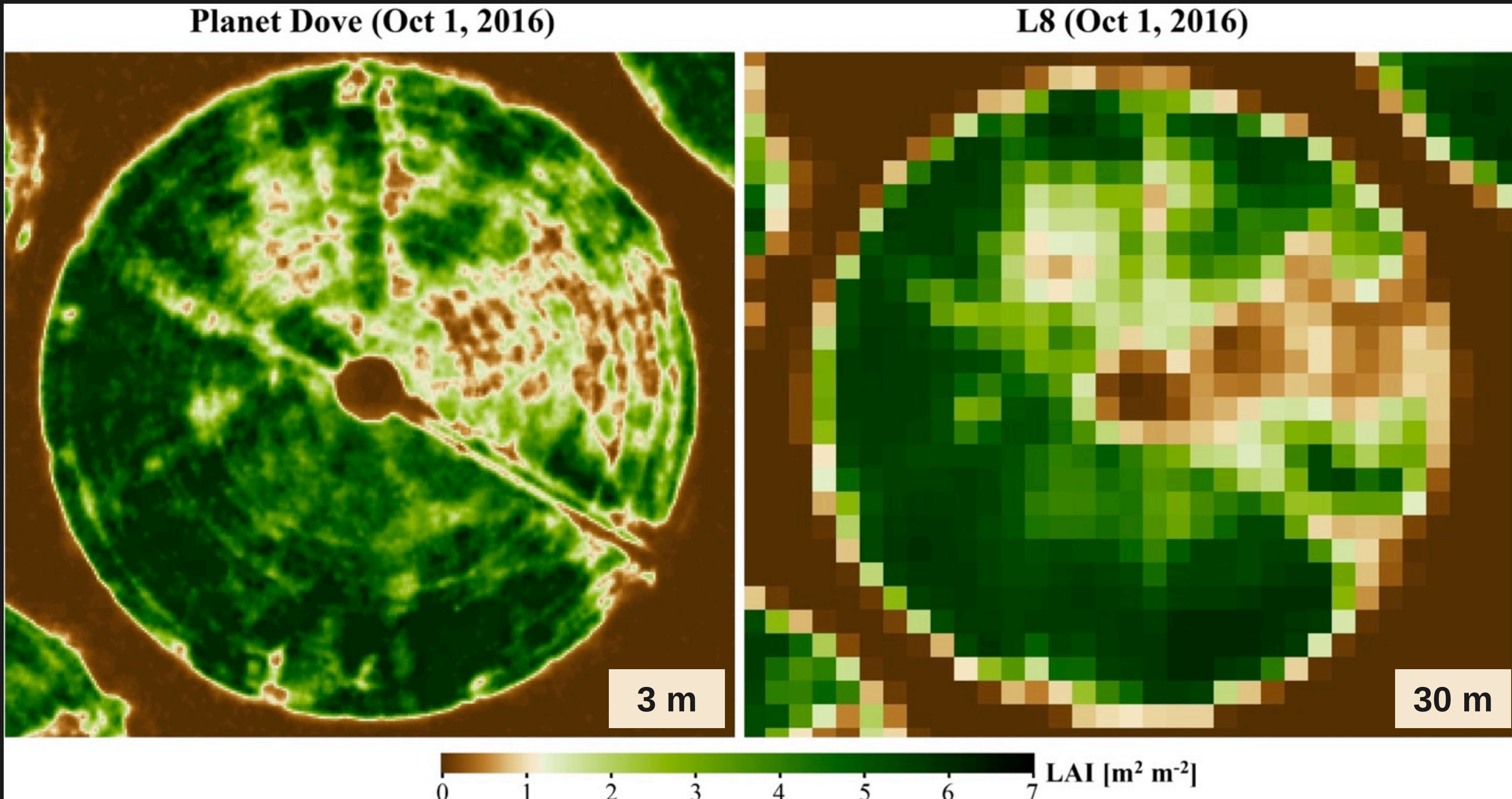
ENHANCED EARTH OBSERVATION FROM CUBESATS – RESOLUTION IMPROVEMENTS



CESTEM EXTENSION: DERIVING HIGH RESOLUTION LEAF AREA INDEX



CESTEM EXTENSION: DERIVING HIGH RESOLUTION LEAF AREA INDEX



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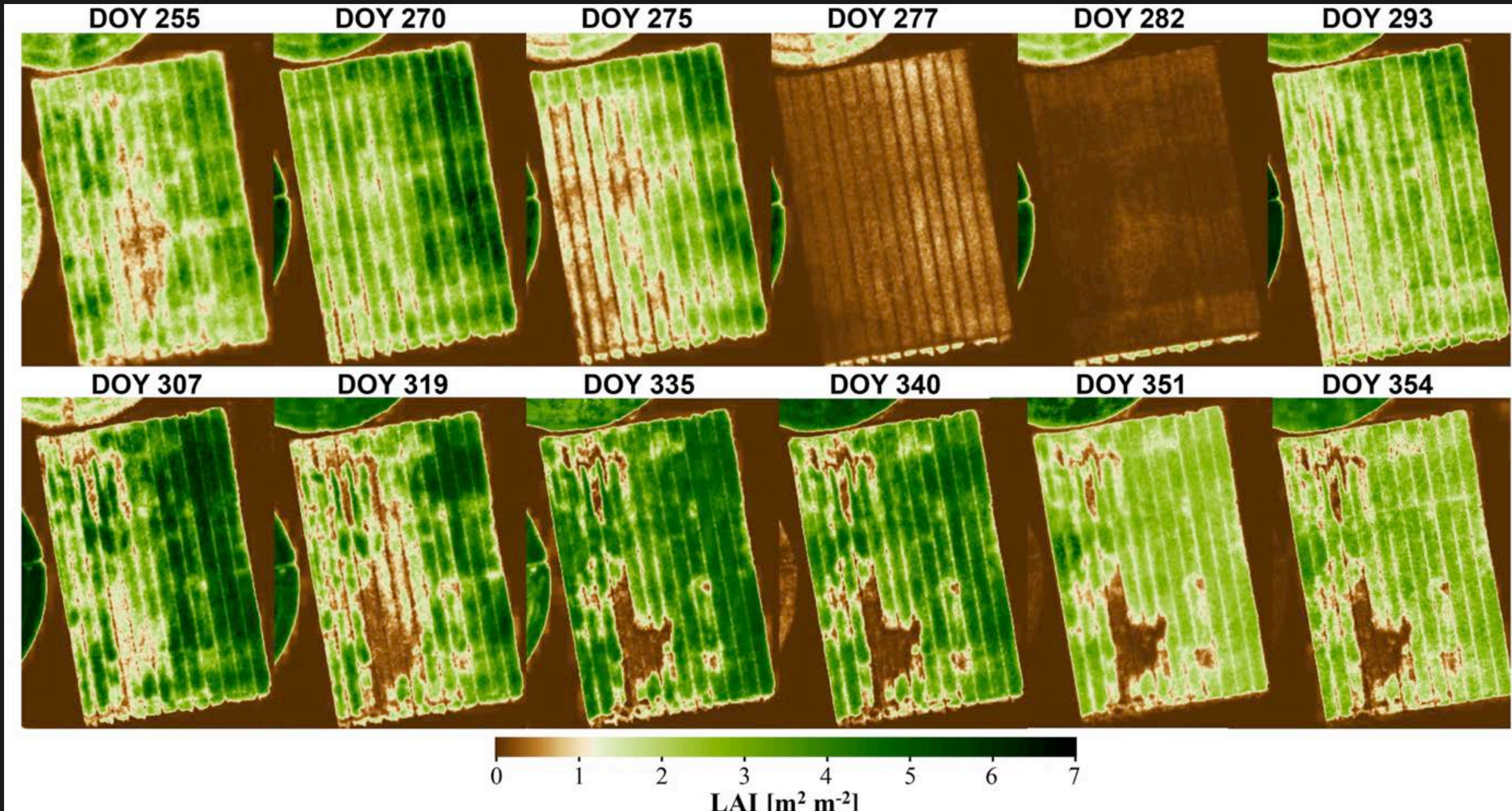
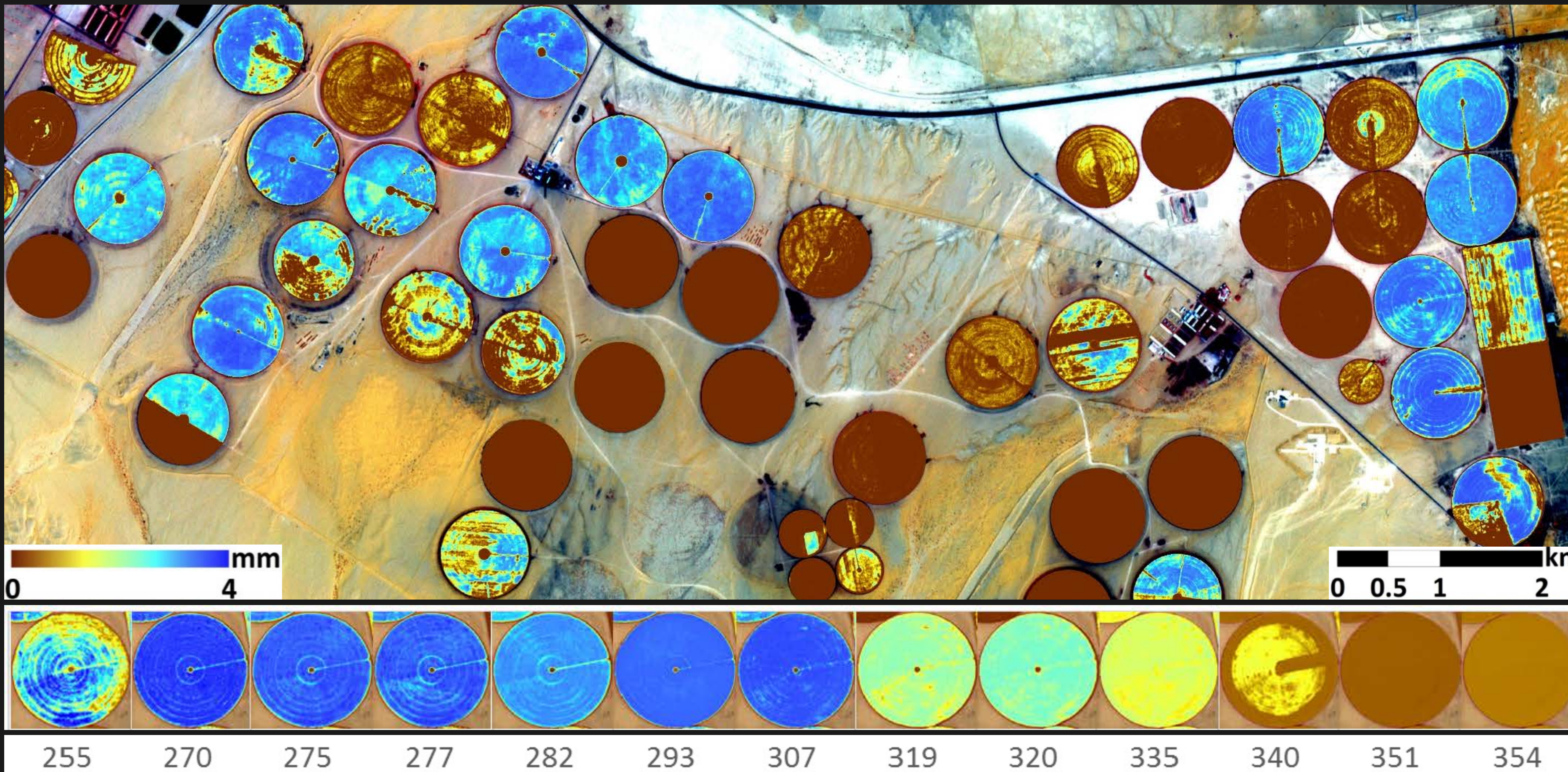


APPLICATIONS OF NEW CUBESAT DATA – CROP WATER USE ESTIMATION

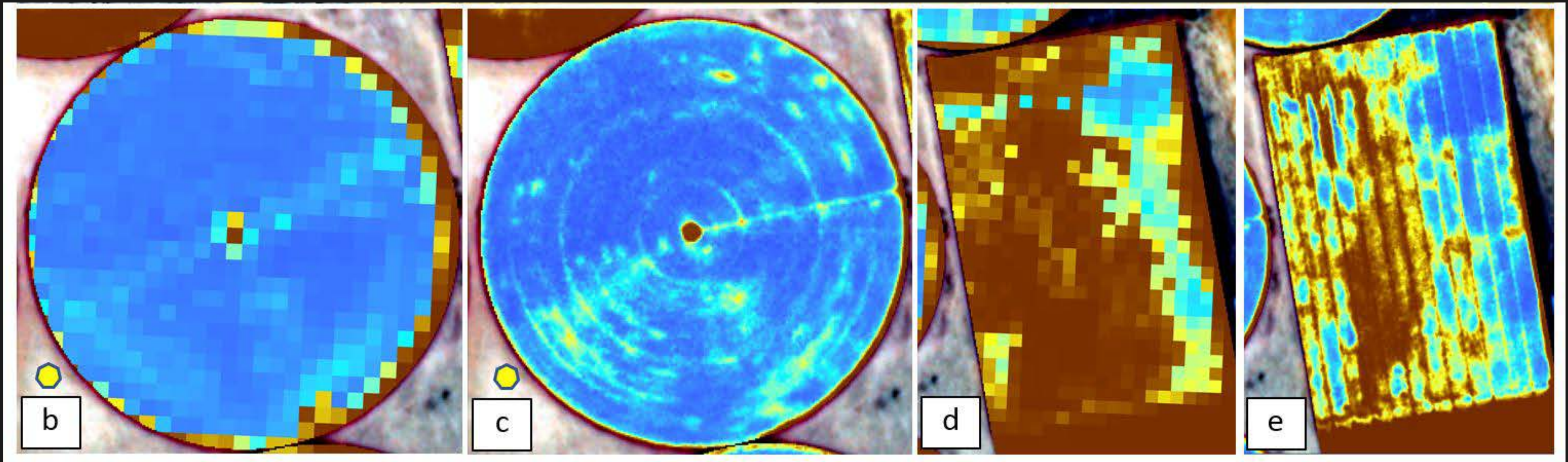
Combining high-resolution LAI and NDVI with ground-based meteorological data enable
estimation of crop-water use: determined here using a simplified Priestley-Taylor approa



APPLICATIONS OF NEW CUBESAT DATA – CROP WATER USE ESTIMATION

These new data sources present a range of opportunities – but also limitations:

- Offer spatio-temporal resolutions largely unmatched by (*accessible*) government platforms
- Commercial sensing driven by different motive ($$) - but not a barrier to overlapping interests
- There are issues (some discussed) - but more opportunities than challenges



McCabe et al. 2017 "Cubesats in hydrology: ultra-high resolution insights into vegetation and terrestrial evaporation" *WRR (submitted)*

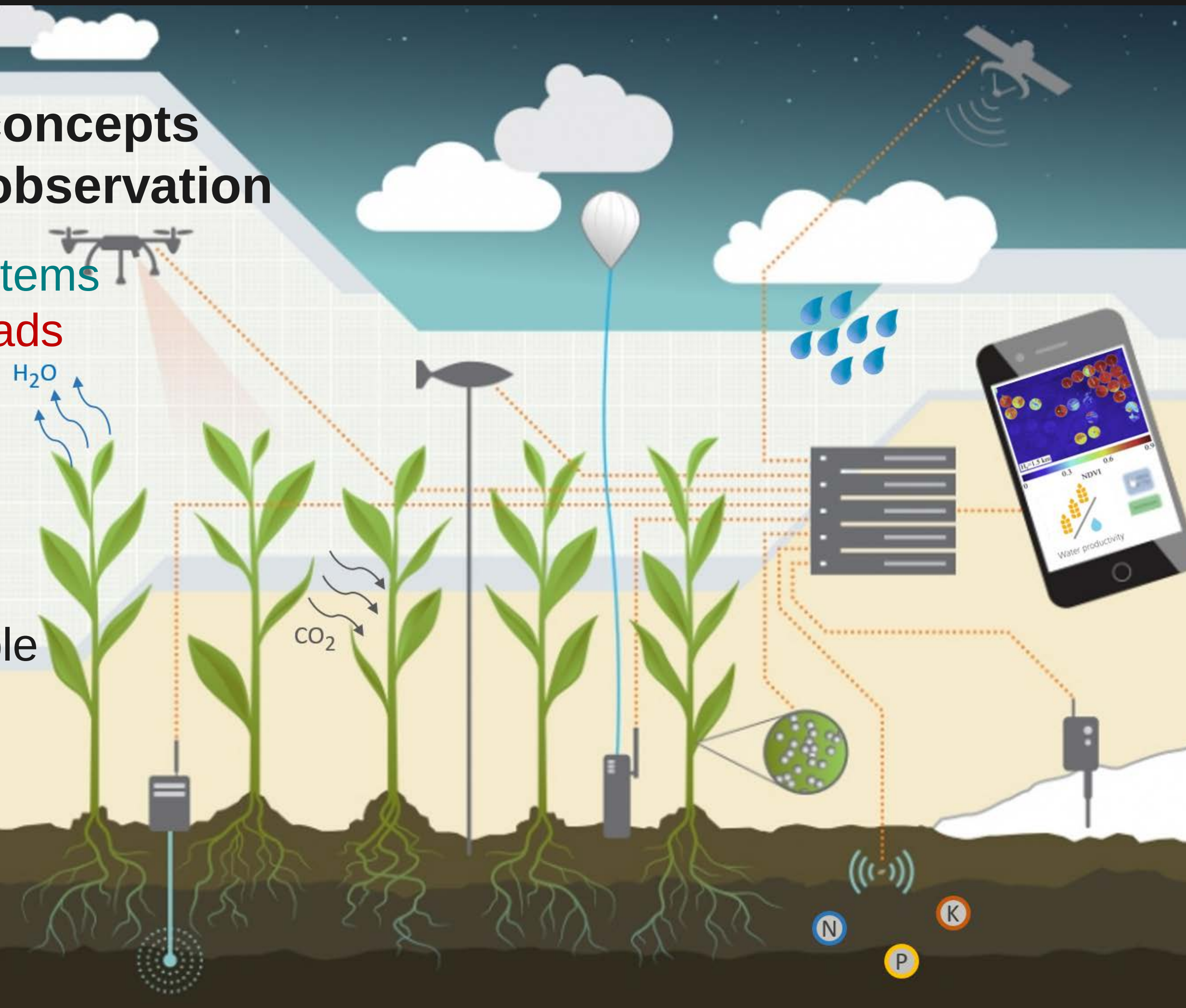
EMERGENT TECHNOLOGIES

UNMANNED AERIAL VEHICLES

NEARER-TO-EARTH REMOTE SENSING FOR HYDROLOGY & PRECISION AGRICULTURE

UAVs are recasting the concepts behind traditional earth observation

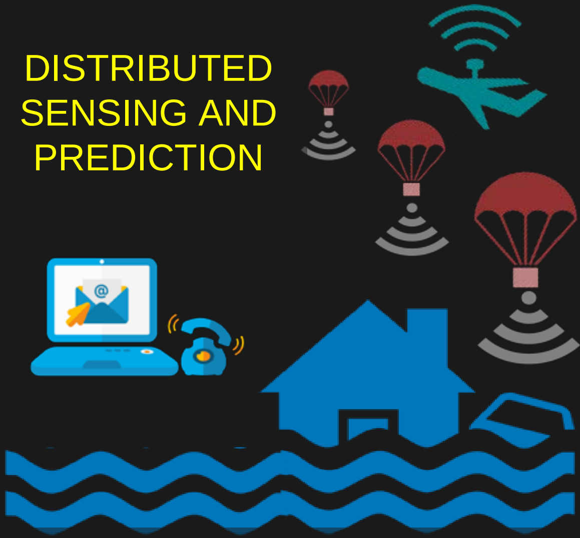
- Comprehensive sensor systems with interchangeable payloads
- Provide ultra-resolution with high-temporal retrieval
- Taskable and on-demand
- **Caveat**: require considerable expertise and sensor calibration/characterization



UNMANNED AERIAL VEHICLES FOR HYDROLOGY AND PRECISION AGRICULTURE


Urban hydrology and civil engineering planning


Water quality (and precipitation) sampling



Real-time flood monitoring and prediction

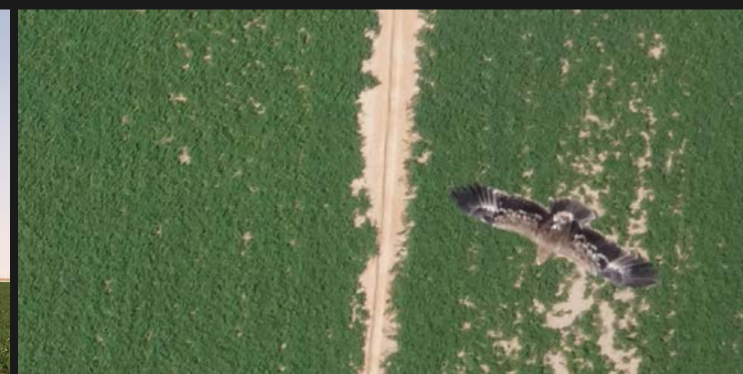

3D modeling of landscapes

A REVOLUTION IN EARTH OBSERVATION

- K A U S T -

HALO Laboratory

With unmatched spatio-temporal resolution, UAVs provide capacity for multi-sensor configurations, providing full-spectrum retrieval options & new insights into process response.



AN ADVANCED SENSOR CAPABILITY

- HALO operates a comprehensive sensor package with interchangeable payloads
- Need to develop the tools and techniques to translate the technology into application
- Available commercial off-the-shelf systems: but all require significant post-processing

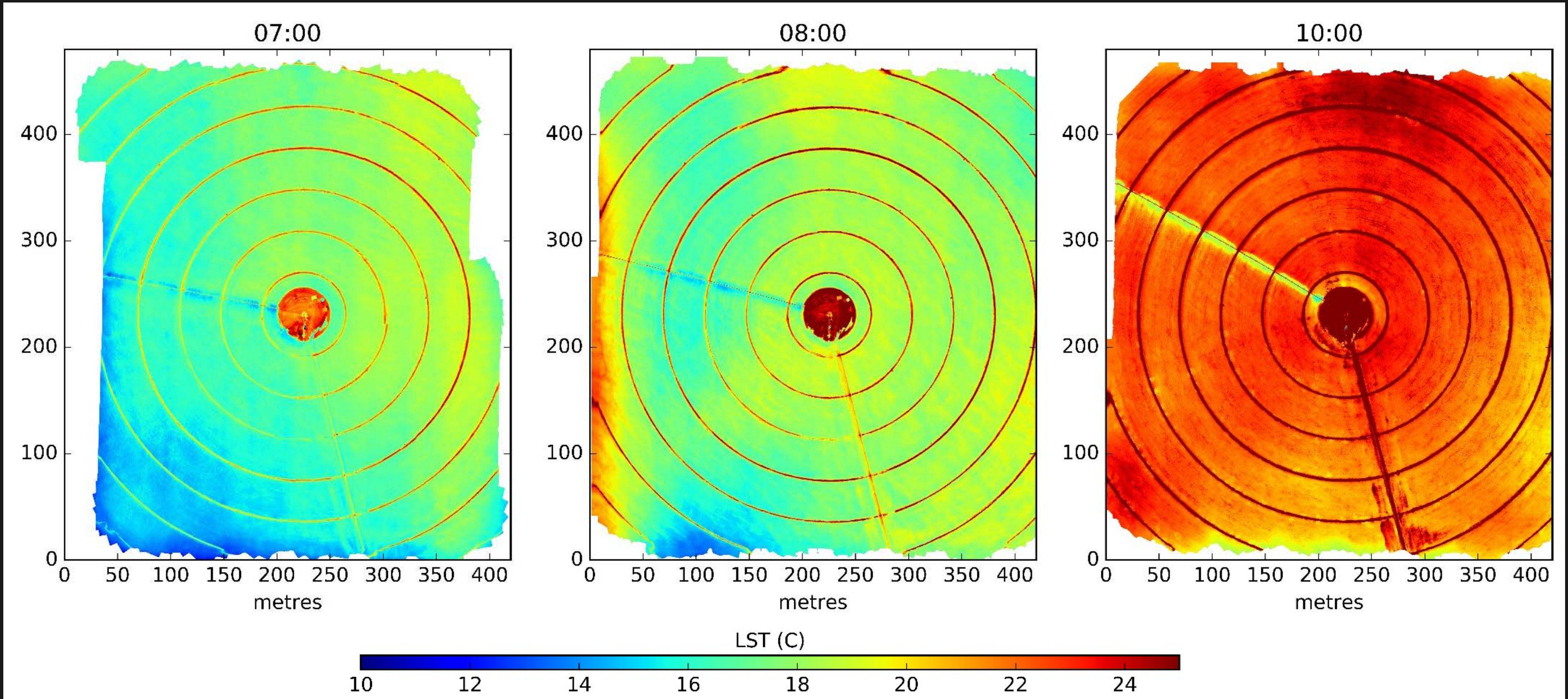
SONY NEX-7 Digital Camera
- 24MP
- interchangeable lens
- 560 grams

Tetracam microMCA 6 bands
- 490,560,665,705,740,865 nm
- Replicate Senintel 2/Landsat
- 700 grams

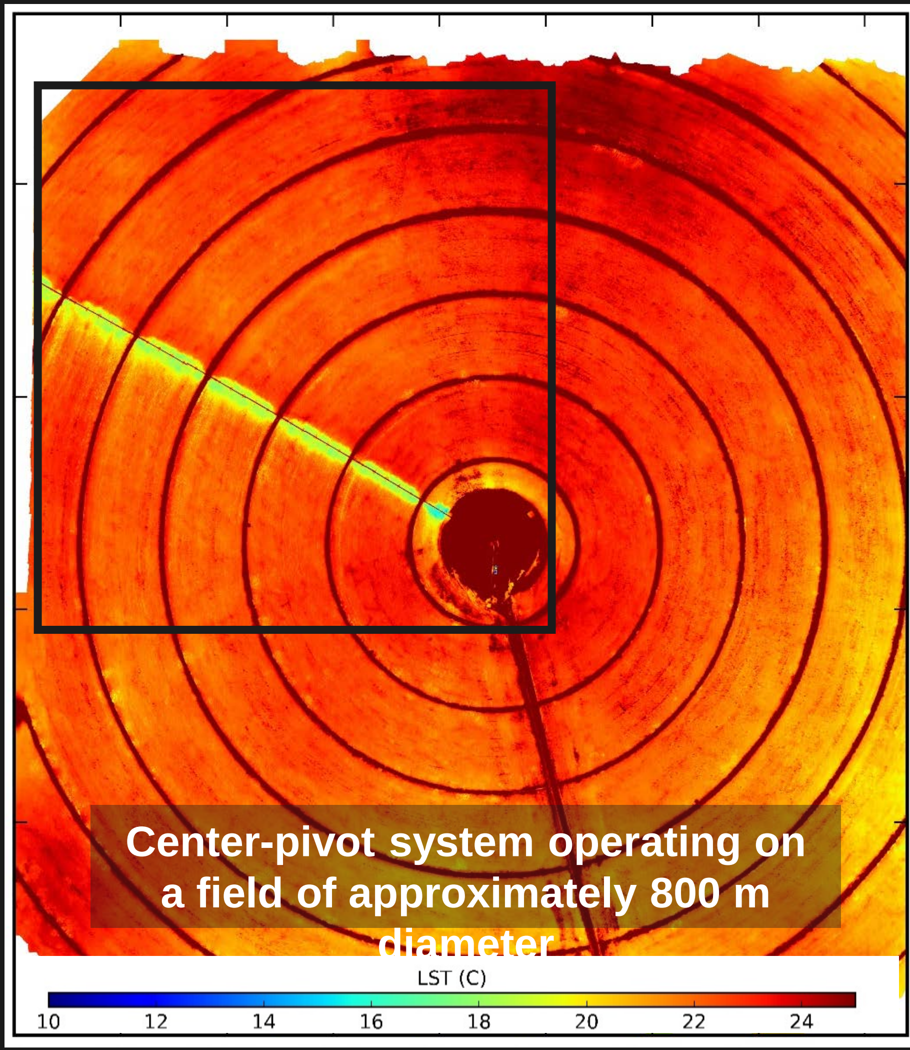
HeadWall Nano-Hyperspec
- 270 spectral bands
- 400-1000nm & 640 spatial
- 600 grams

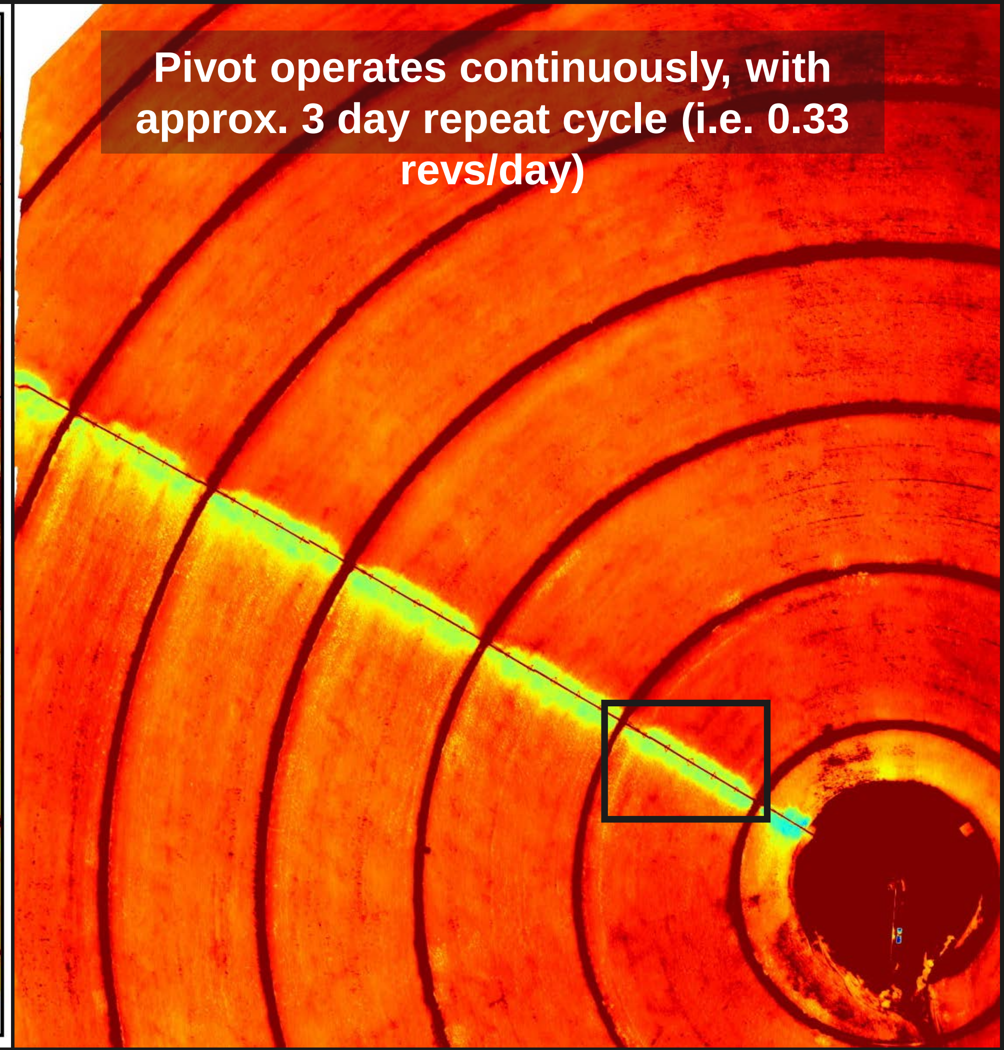
TeAx ThermaCapture (FLIR Tau)
- 7.5-13 µm (broadband)
- 640 x 480
- 45 grams

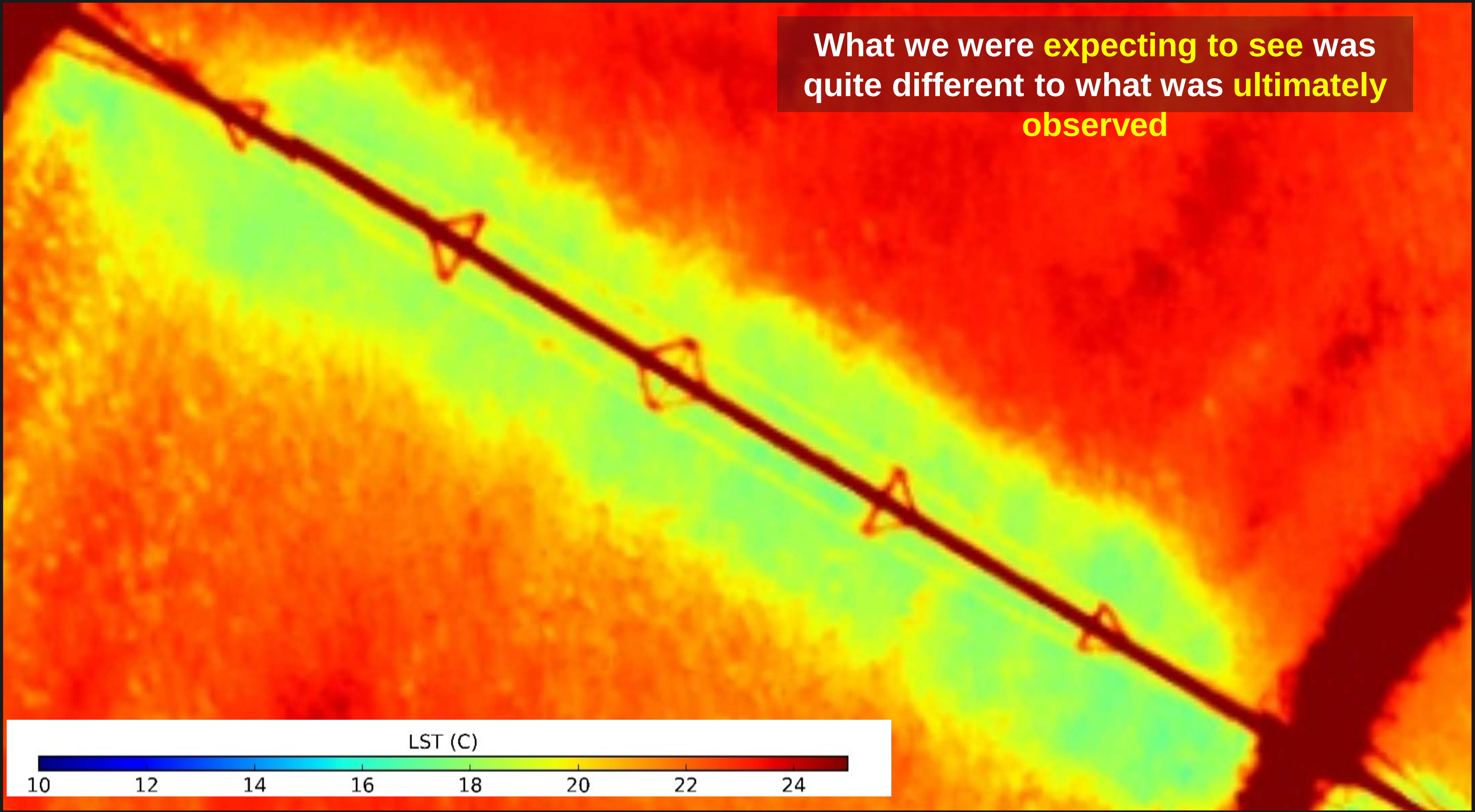
UAVs are reinventing traditional satellite-based EO, providing hyper-resolution observat
and an unrivalled temporal context. **What new process insights can be determined?**

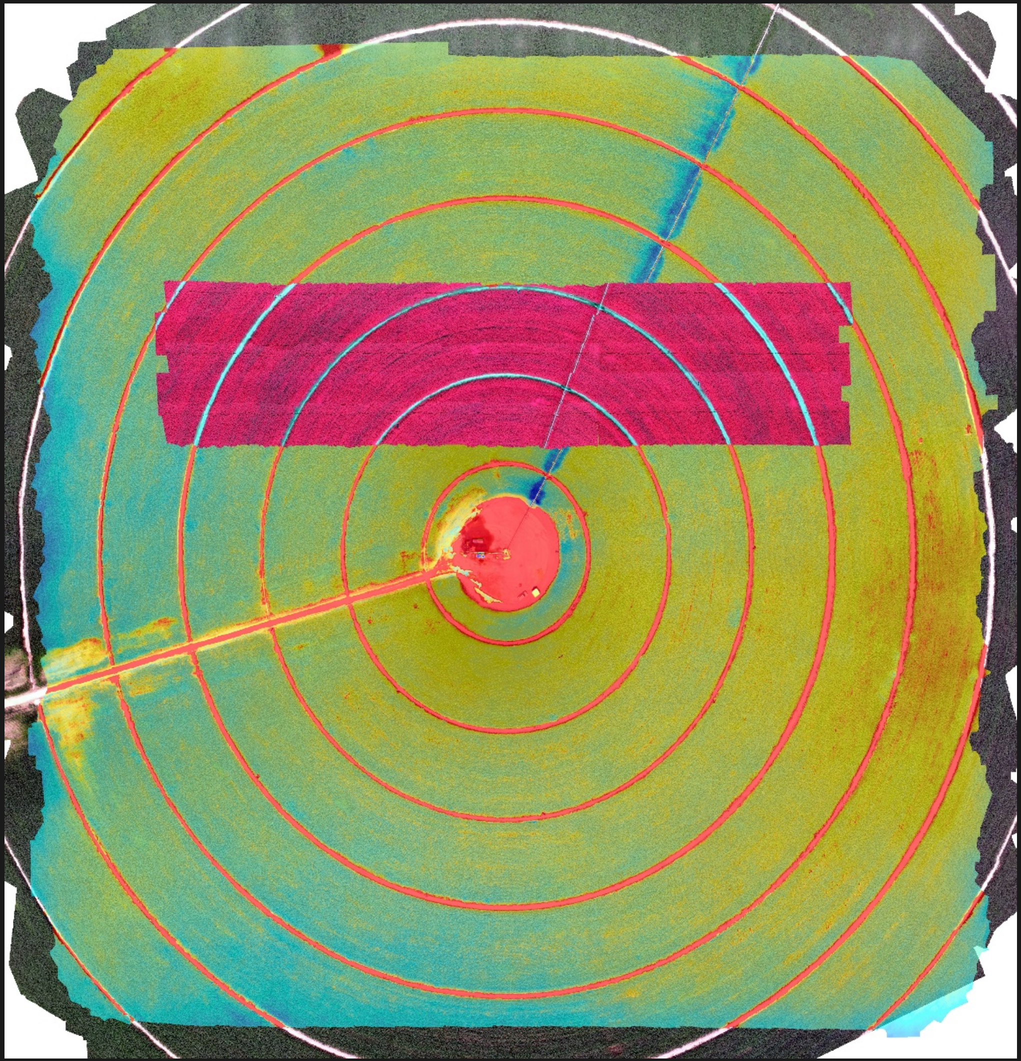


UNMANNED AERIAL VEHICLES FOR HYDROLOGY AND PRECISION AGRICULTURE





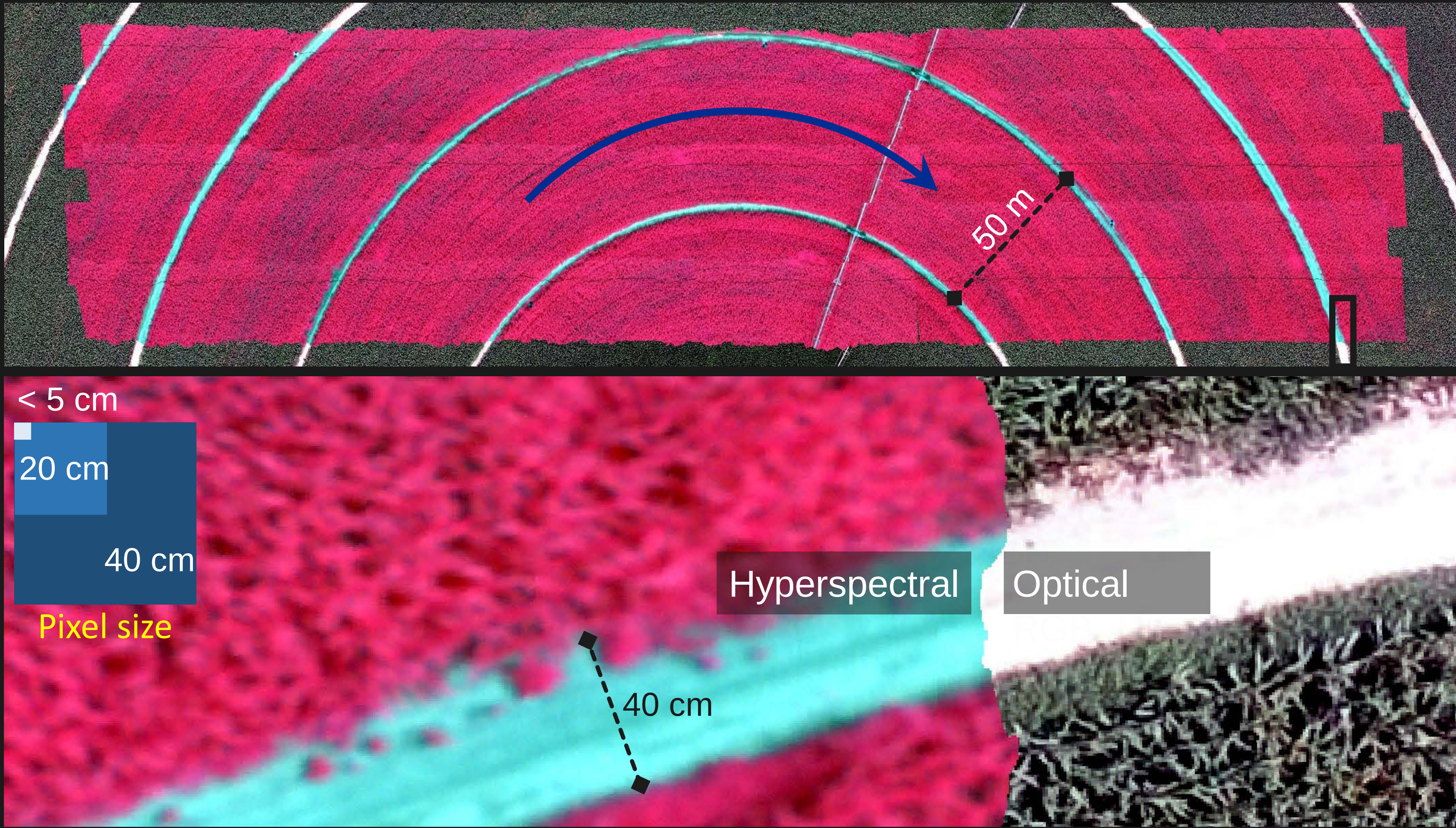

What we were expecting to see was quite different to what was ultimately observed
LST (C)
10
12
14
16
18
20
22
24



MULTI-SENSOR UAV RETRIEVALS

UAVs provide capacity to observe across the VNIR to thermal-infrared:

- Requires new modeling approaches to exploit synergistic observations
- Develop new insights into coupled H_20-C-energy interactions
- Exploit full-spectrum to derive enhanced vegetation metrics of stress, health etc
- Retrieval of chlorophylls, carotenoids…


50 m
< 5 cm
20 cm
40 cm
Pixel size
Hyperspectral
Optical
40 cm

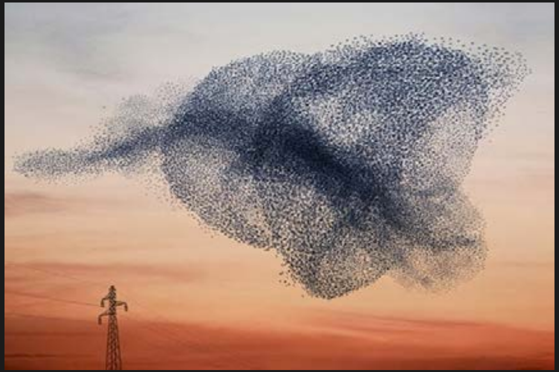
UAVS WILL CHANGE HOW WE OBSERVE THE EARTH

- Rapid advances in sensor miniaturization and autonomous operation
- Increasing range of instrumentation, flight time and processing solutions
- Observation-swarms versus distributed-everywhere??

EVERYTHING

EVERYWHERE

ALL THE TIME



S THE FUTURE OF REMOTE SENSING IN-SITU

CHALLENGES AND OPPORTUNITIES

FINDING THE SIGNAL IN THE NOISE

A FUTURE EARTH OBSERVATION PLATFORM: LIVE TO YOU IN HD

HYDROLOGY ON DEM

STREAMING FROM SPAC

VIDEO: an unprecedented observa

- How might hydrology harness this d
  - Flood monitoring and forecastin
  - Weather dynamics
  - Water quality and hydrodynamic
  - ….other approaches?
- Are we prepared for this new wave

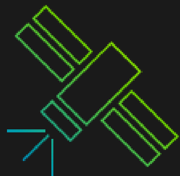
urthecast

Terra

A FUTURE EARTH OBSERVATION PLATFORM: LIVE TO YOU IN HD

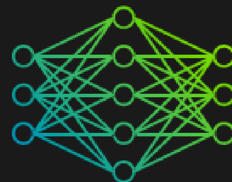
BIG DATA ANALYTICS AND ACTIONABLE INTELLIGENCE

Infographic derived from https://orbitalinsight.com/



Geospatial data follows Moore's Law

+

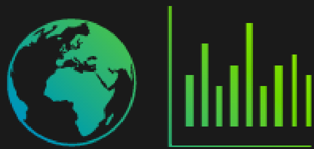


Machine visualization and learning

+

Parallel computing moves to the cloud

=

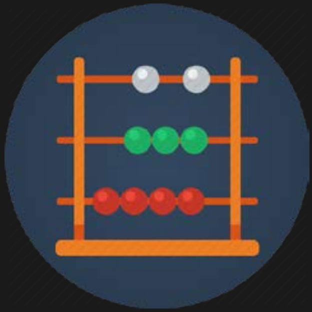


Decision support and management outcomes

What is the hydrological equivalent to the Walmart Parking Lot Problem?

Parking lot of Oak Park Mall, Overland Park, KA

MONITOR



ANALYZE

PREDICT

THE CRYSTAL BALL SLIDE

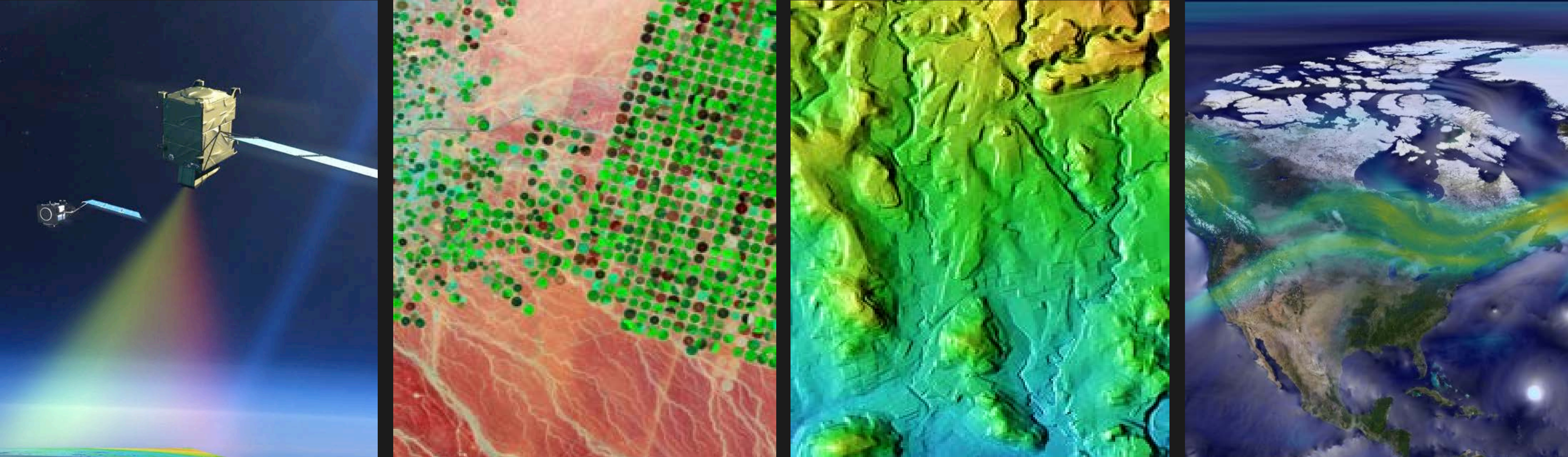
1. Are we using $$$ or current satellites platforms effectively: is this model sustainable?

2. Miniaturization, COTS, orbital price per pound drops:
commercial partnerships and PI-driven initiatives!

3. We probably need to rethink how we do hydrology:
role of non-traditional sensing (in time and space)

4. Technology is out-pacing our applications:
i.e. science is lagging the potential opportunities

5. Community needs to be prepared for a deluge of data:
video, hyper-res/spec, data-analytics…we are not



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