

Terrain-AI

Rowan Fealy & Tim McCarthy

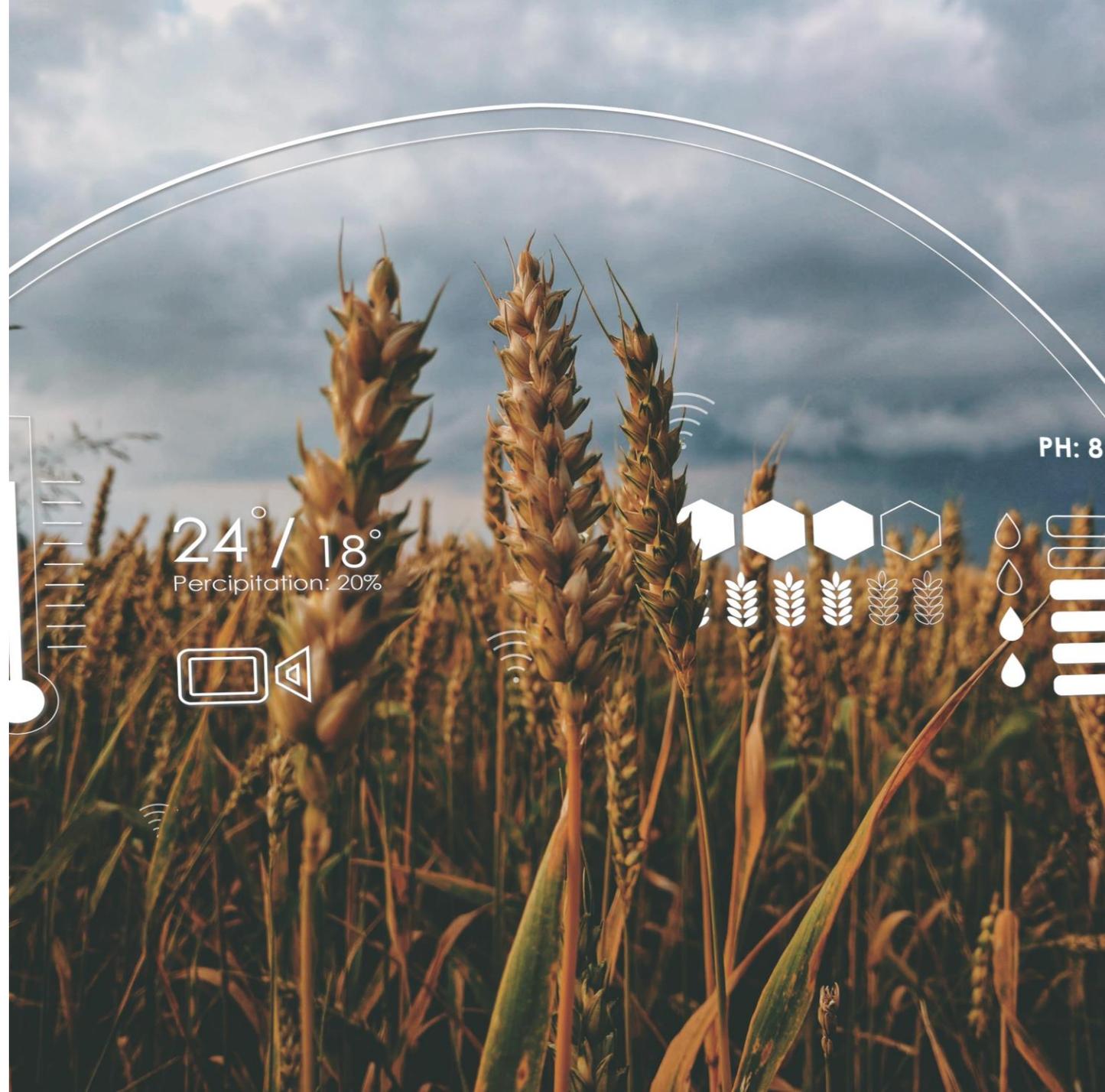
"This material is based upon works supported by Terrain-AI (Uncovering new insights to support effective climate change decision-making) SFI 20/SPP/3705 which is funded under the Science Foundation Ireland Strategic Partnership Programme"



Terrain AI Project

Mission - *Provide a direct response to Climate Change, seeking to develop innovative sensing, computational and modelling methodologies in capturing and processing data about the world around us.*

The overall aim is to develop innovative sensing and computational methodologies – to capture and process data about the world around us - in order **to significantly improve our understanding of the complex interactions and associated impacts of natural processes and human activities** through an integrated and whole systems modelling approach



T-AI Partnership

Industry



European Agencies



Core Research Partners



Innovation, End-Use Cases, Usefulness

Context, Goals, Strategy, Relevance, Funding

Associations/Community Groups



Government Depts/Agencies



Terrain-AI: Key Research Challenges & Questions

Estimating terrestrial carbon emissions/removals is non-trivial due to a number of factors including; **complexities in determining highly variable soil carbon stocks** and the slow (decadal) rate of change in these stocks (Oertel et al., 2016; Todd-Brown et al., 2013); **terrestrial ecosystems are complex, dynamical biological systems** representing multiple sources and sinks; **sparse measurement networks; limited in-situ data** (e.g. no. of sites, long term, etc.); and, **globally fragmented data and modelling infrastructure** (Paustian et al., 2019; Smith et al., 2020), all of which **give rise to a high level of uncertainties in accurately estimating carbon sources and sinks** (Krug, 2018). In addition, capturing **spatio-temporal human behaviour and dynamic management activities**, essential to understanding and managing terrestrial carbon stocks and fluxes (Zimmerman et al., 2007), is extremely challenging.

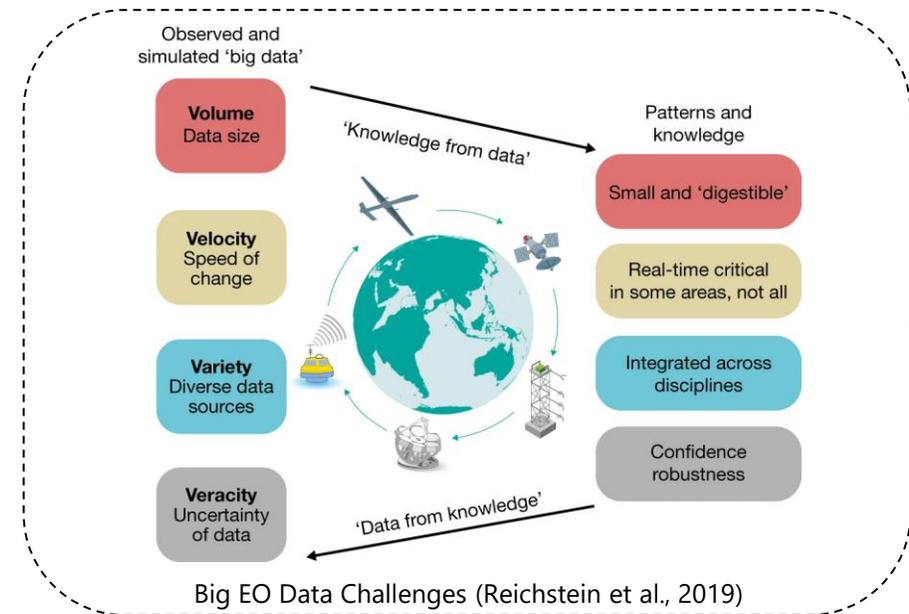
Currently, **petabytes of satellite Earth observation (EO) data are freely available**. However, the full information potential of EO data has not been yet realized because many **big data challenges and complexity barriers hinder their effective use**. Consequently, facilitating the production of EVs using the wealth of satellite EO data can be beneficial for environmental monitoring systems (Giuliani et al., 2020).

Petabyte scale EO Data Platforms

How can large volumes of field sensor datastreams, conventional geospatial databases and relatively recent EO/drone datasets be captured, collated, and fused with novel ML algorithms in order to generate higher quality information regarding various terrestrial environments (e.g. Grasslands, Forests, Peatlands) and **associated dynamic human activity**.

Integrated Earth System Modelling

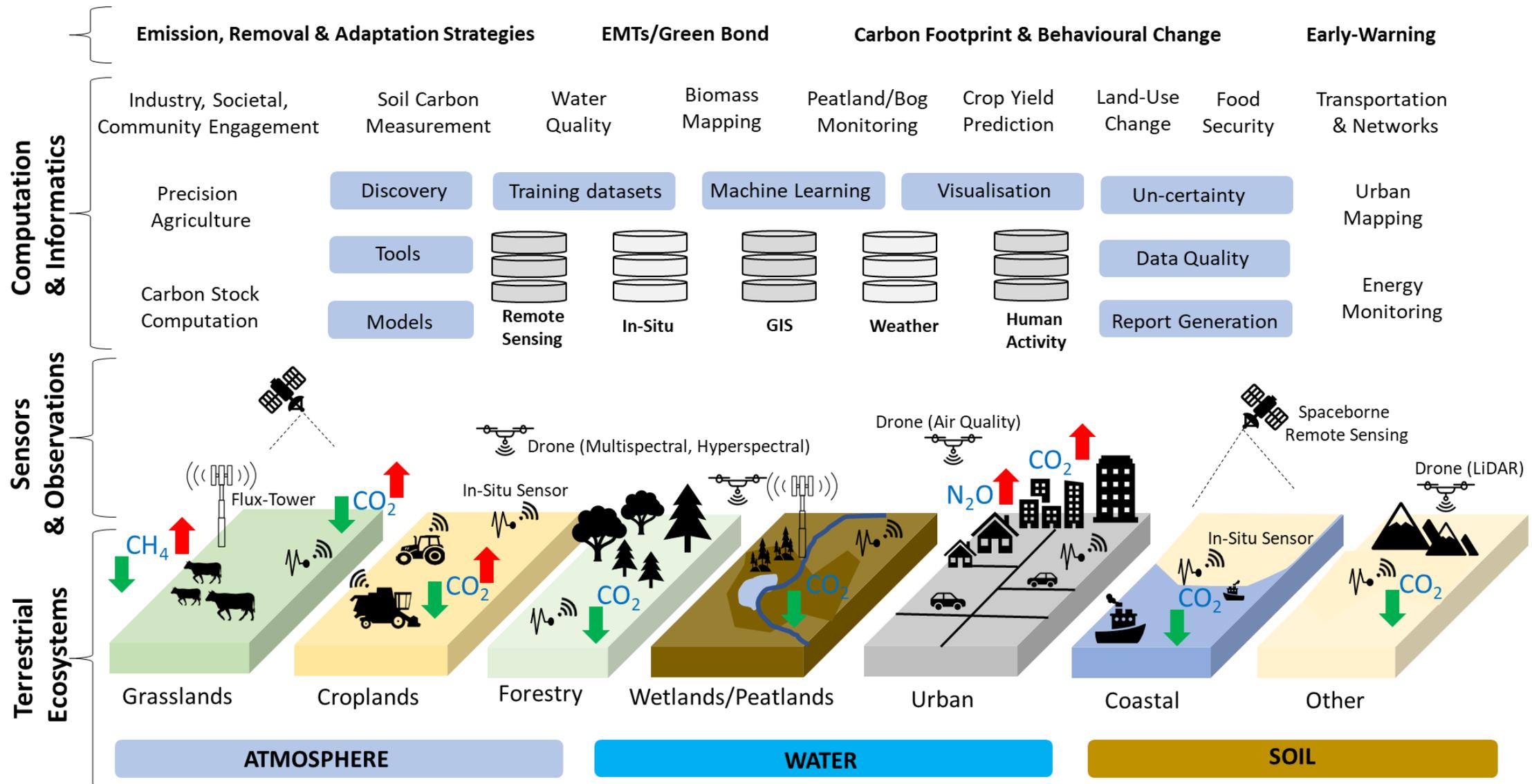
How can improved information on land-use and activity be used to advance the current state of the art model based estimates of terrestrial carbon stocks and fluxes, at a hierarchy of spatial and temporal scales, required to support more effective decision making and policy formulation.



Modeling system	Citation	Human component	Earth system component	Data: Human to Earth	Data: Earth to Human
DICE	Nordhaus (1993)	Ramsey growth model	Simple box model	CO ₂ emissions	Temperature
GUMBO	Boumans et al (2002)	Anthrosphere module	Atmosphere, Lithosphere, Hydrosphere, and Biosphere modules	CO ₂ emissions, Gross World Ecosystem services Product	
GOLDMERGE	Bahn et al (2006)	MERGE	C-GOLDSTEIN	CO ₂ concentration	Temperature
IGSM	Reilly et al (2007), Monier et al (2013a, 2013b, 2015, 2018)	EPPA	EMIC based on CLM/TEM/CAM	GHG emissions, land use/land cover	Productivity, trace gases
IMAGE-CNRM	Voltaire et al (2007)	IMAGE	CNRM	GHG emissions, aerosol emissions, land cover	Temperature, precipitation
Jarvis	Jarvis et al (2012)	Single equation	ACCC	CO ₂ emissions	Temperature
CLM*	Leng and Tang (2014)	Statistical relationship	CLM	Irrigation water demand	Precipitation
iESM	Collins et al (2015), Thornton et al (2017)	GCAM	CESM	CO ₂ emissions, land use/land cover	Ecosystem productivity
PRIMA	Hejazi et al (2015), Scott et al (2016), Voisin et al (2017)	GCAM-USA	RESM + MOSART	Water demand	Crop yield, HDD/CDD
BNU-HESM	Yang et al (2015, 2016)	DICE	BNU-ESM	CO ₂ emissions	Temperature
CSM	Beckage et al (2018)	Social behavior model-extreme events focus	C-ROADS	GHG emissions	Temperature

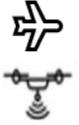
Integrated modeling systems included in this review. Modeling systems are ordered chronologically by date of first publication (Calvin and Bond-Lamberty, 2018)

Terrain-AI Platform

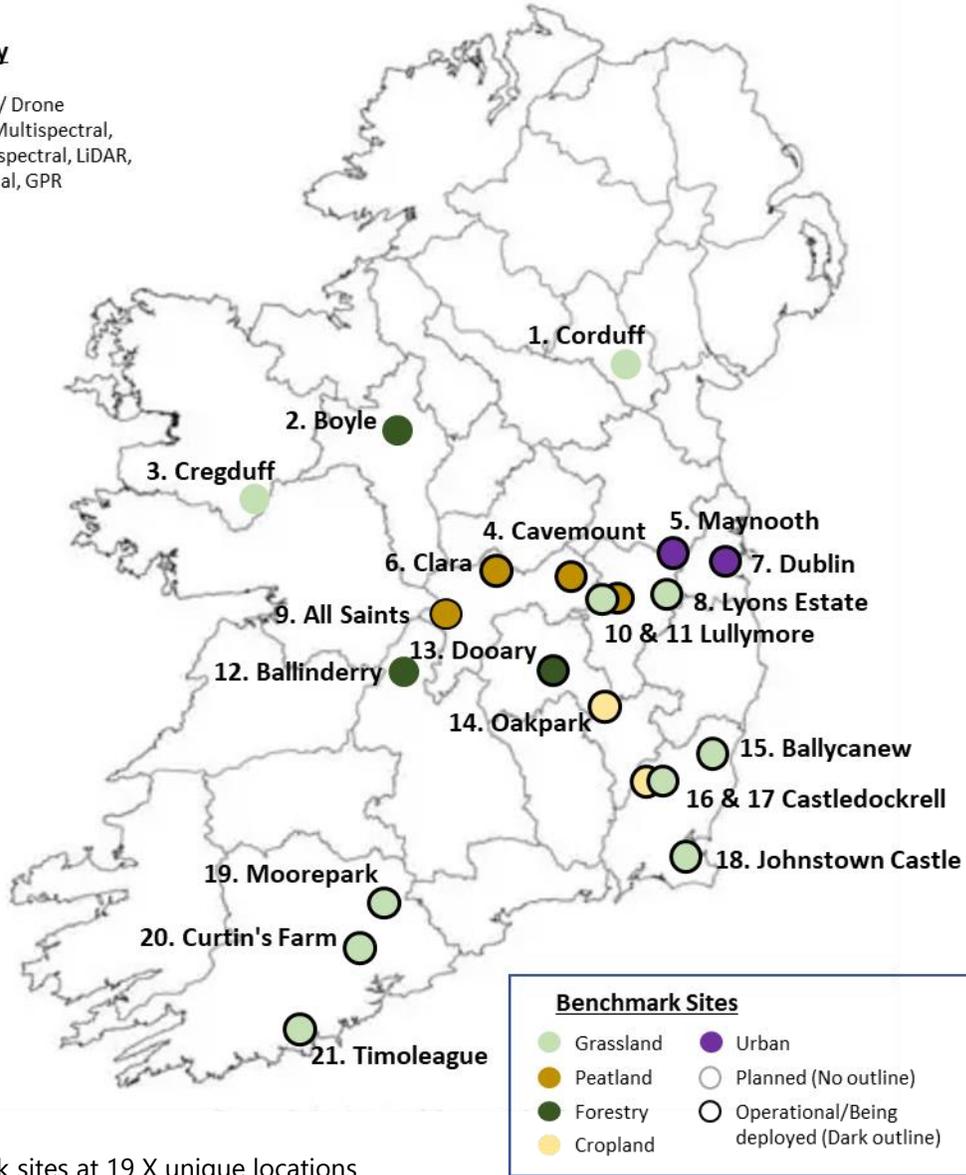


Benchmark Sites

Aerial Survey



Aerial / Drone
RGB, Multispectral,
Hyperspectral, LiDAR,
Thermal, GPR

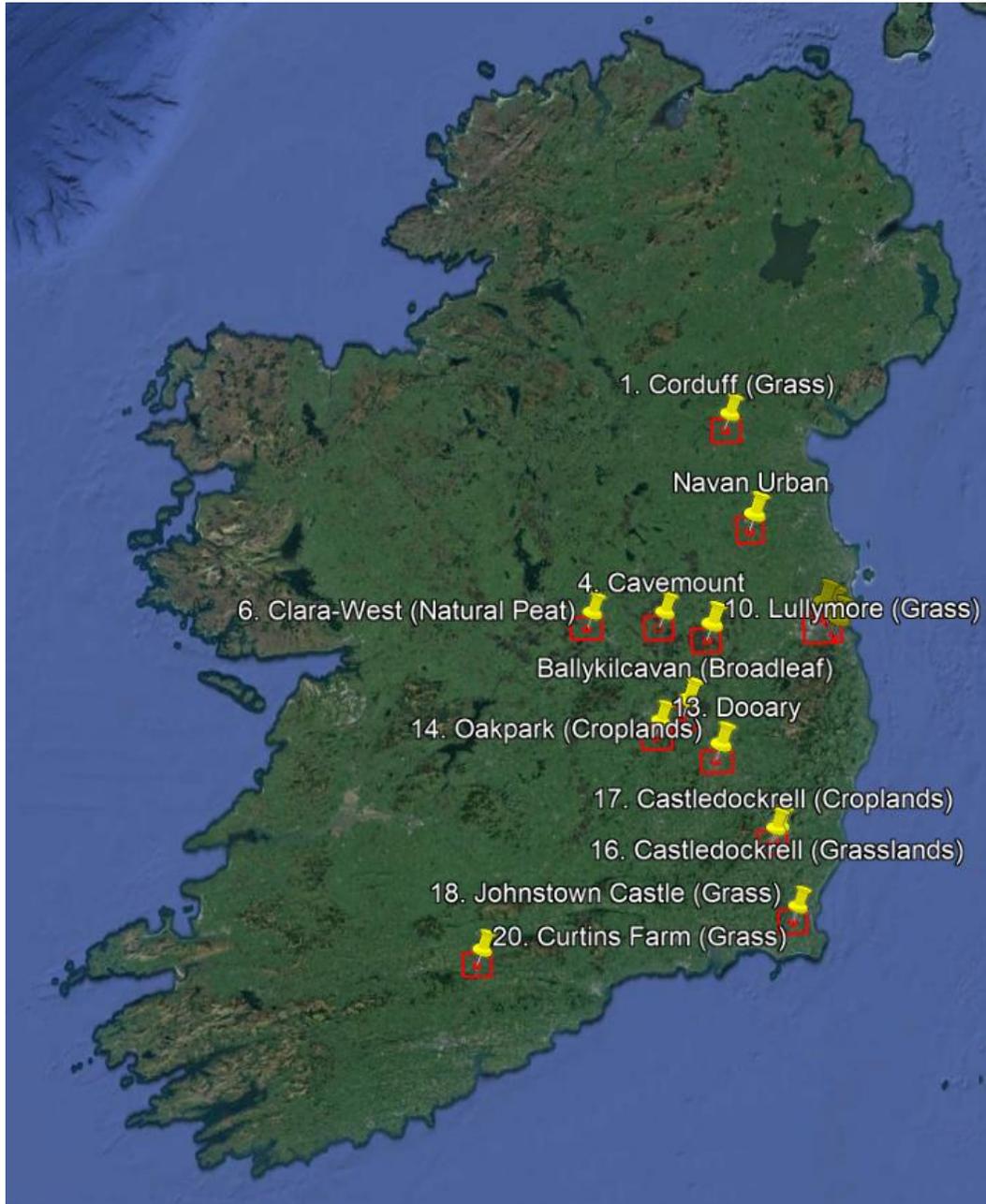


* 21 benchmark sites at 19 X unique locations

ID	Site	Flux Tower	Weather Station	Soil Chamber	Mgt & Ancillary Data	Aerial & Drone
1	Corduff (Grass) TBC	✓	✓		✓	✓
2	Boyle (Broadleaf) TBC	✓				✓
3	Cregduff (Grass) TBC	✓	✓		✓	✓
4	Cavemount	✓		✓	✓	✓
5	Maynooth (Urban)		✓		✓	✓
6	Clara	✓		✓	✓	✓
7	Dublin		✓		✓	✓
8	Lyons Estate		✓		✓	✓
9	All Saints	✓			✓	✓
10	Lullymore (Grass)	✓			✓	✓
11	Lullymore (Peat)	✓		✓	✓	✓
12	Ballinderry (Coniferous) TBC	✓		✓		✓
13	Dooary (Coniferous)	✓			✓	✓
14	Oakpark		✓		✓	✓
15	Ballycanew	✓	✓		✓	✓
16	Castledockrell (Crop)	✓	✓		✓	✓
17	Castledockrell (Grass)	✓	✓		✓	✓
18	Johnstown Castle	✓	✓		✓	✓
19	Moorepark	✓	✓		✓	✓
20	Curtin's Farm	✓				✓
21	Timoleague	✓	✓		✓	✓

Instrumentation/sites/live stream data provided by the following: National Agricultural Soil Carbon Observatory (NASCO); National Parks and Wildlife Service; T-AI

T-AI : Aerial Surveys : 15 X test-sites (Level-1)



Test-Site Name	Habitat-Type	Area (ha)	Photogrammetry	Multispectral	LiDAR	Total Surveyed Hectares	Photogrammetry	Multispectral	LiDAR	Total Processed Hectares
Navan	Urban	581	1	Acquired same time as LiDAR	1	1162	1	1	1	1743
Dublin-A	Urban	795	1	Acquired same time as LiDAR	1	1590	1	1	1	2385
Dublin-B	Urban	158	1	Acquired same time as LiDAR	1	316	1	1	1	474
Dublin-C	Urban	426	1	Acquired same time as LiDAR	1	852	1	1	1	1278
Dundrum	Urban	426	1	Acquired same time as LiDAR	1	852	1	1	1	1278
Clara	Peatland (Natural)	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Cavemount	Peatland (ReHab)	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Ballykilcavan	Forestry (Broadband)	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Dooary	Forestry (Coniferous)	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Oakpark	Croplands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Castledockrell	Croplands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Castledockrell	Grasslands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Johnstown	Grasslands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Curtins Farm	Grasslands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Corduff	Grasslands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Lullymore	Grasslands	500	1	Acquired same time as LiDAR	1	1000	1	1	1	1500
Sub-Totals		7,460				14,920				22,380

Dublin (Urban) 3 X sites



Navan (Urban) 1 X site



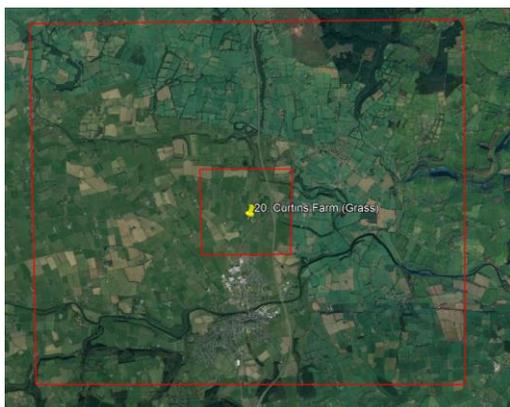
Cavemount (Peatlands – ReHab) 1 X site



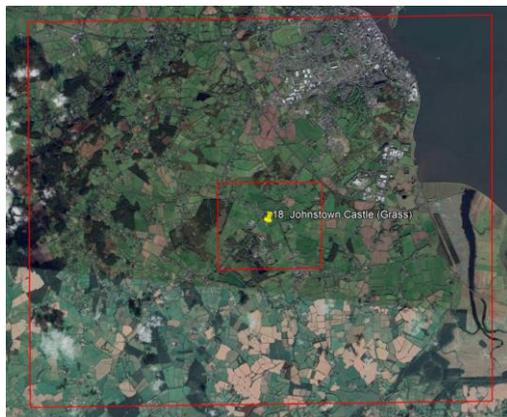
Clara (Peatlands – Natural) 1 X site



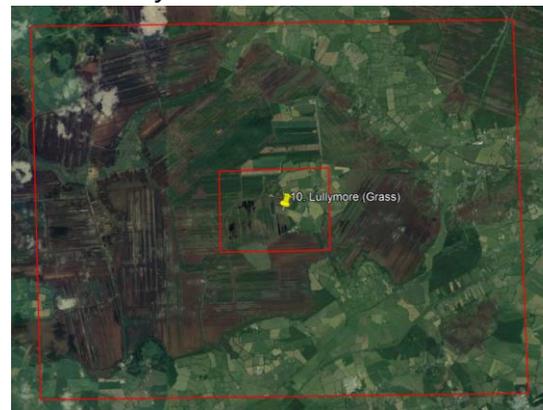
Curtins Farm(Grasslands) 1 X site



Johnstown Castle (Grasslands) 1 X site



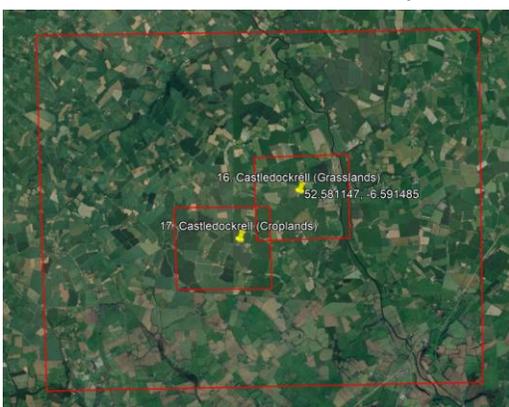
Lullymore (Grasslands) 1 X site



Corduff (Grasslands) 1 X Site – TO BE CONFIRMED



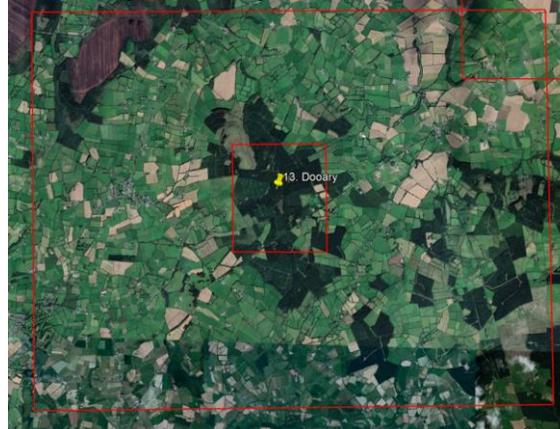
Castledockrell (Grasslands & Croplands) 2 X sites



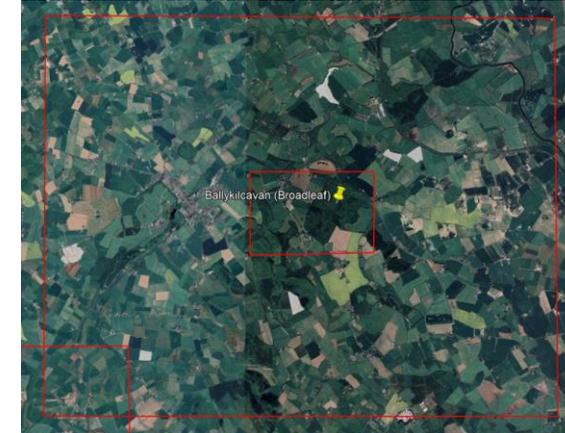
Oakpark (Croplands) 21 X site



Dooary (Forestry - Coniferous) 1 X site



Ballykilcavan (Forestry - Broadleaf) 1 X site



Work-Package Overview



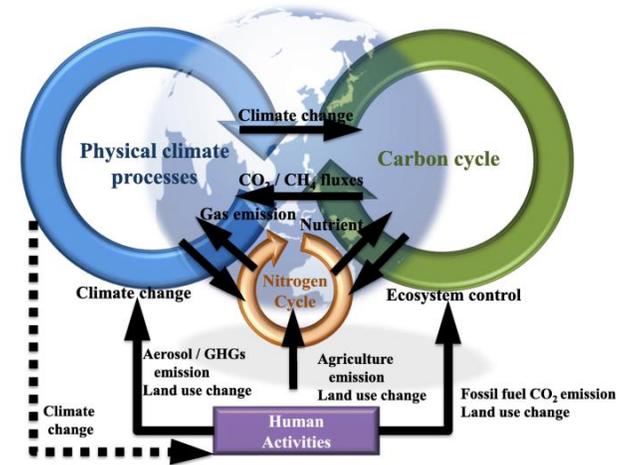
WP5 Digital Products & Information Services

Toolkits & Digital Information

- Soil Carbon Monitoring Toolkit
- Grassland Biomass Measurement
- Automated Urban Building Classifier
- Regional Carbon Stocks & Exchange
- *Habitat-Ecosystem* Scenario Modelling

Use-Cases & Information Requirements

Toolkits, Methodologies & Digital Information Services



WP3 Habitat Profiling

Measurements & Analysis

- Soil Properties
- Biomass
- Land Management
- Energy Consumption
- Human Activity

Analyses & Measurements
Observations & Data

WP2 Data Platform

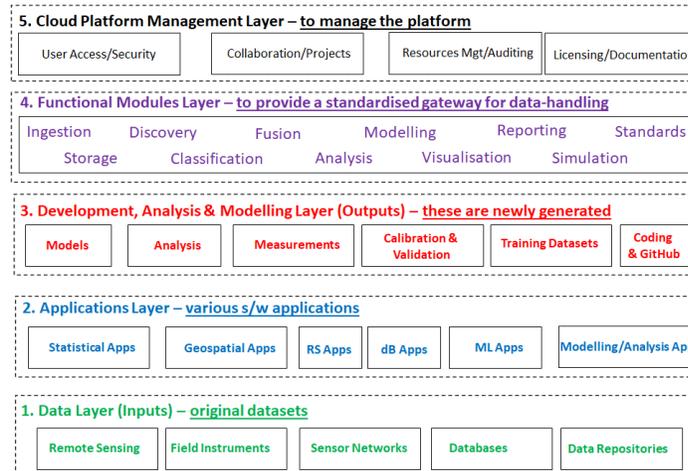
Reference Databases & Datasets

Models
ECVs, Factors

WP4 Earth System Modelling

Integrated Models

- Diagnostic
- Process-based
- Dynamical Land-Surface
- Inverse based



Fundamental EO/GEO Data Platform Components

Terrain-AI: Data Platform

5. Cloud Platform Management Layer – to manage the platform

User Access/Security

Collaboration/Projects

Resources Mgt/Auditing

Licensing/Documentation

4. Functional Modules Layer – to provide a standardised gateway for data-handling

Ingestion

Discovery

Fusion

Modelling

Reporting

Standards

Storage

Classification

Analysis

Visualisation

Simulation

3. Development, Analysis & Modelling Layer (Outputs) – these are newly generated

Models

Analysis

Measurements

Calibration &
Validation

Training Datasets

Coding
& GitHub

2. Applications Layer – various s/w applications

Statistical Apps

Geospatial Apps

RS Apps

dB Apps

ML Apps

Modelling/Analysis Apps

1. Data Layer (Inputs) – original datasets

Remote Sensing

Field Instruments

Sensor Networks

Databases

Data Repositories

Terrain-AI: Data Catalogue

	T-AI Researcher	Domain	Name	URL Link (or More information)	Provider	Year	T-AI Person to investigate	Min. Est. Vol. TBs	Max. Est. Vol. TBs	How to integrate into T-AI Platform
3	0.25GB, SSP + 1GB	Spaceborne	Spaceborne Satellite - Copernicus (S1, S2, S3, SSP)	https://scihub.copernicus.eu/			Paul	15	30	Offline pull-down
4		Spaceborne	Spaceborne Satellite - Landsat	https://scihub.copernicus.eu/			Paul	0.5	2	Offline pull-down
5	Stuart Green	Spaceborne	Teagasc Landsat Archive				Tim	2	2	Image Database?
6	Tim McCarthy	Airborne	Airborne/Drone - Photogrammetry	TBC			Tim	2	5	
7	Tim McCarthy	Airborne	Airborne/Drone - Multispectral	TBC			Tim	2	5	
8	Tim McCarthy	Airborne	Airborne/Drone - Hyperspectral	TBC			Tim	2	5	
9	Tim McCarthy	Airborne	Airborne/Drone - LiDAR	TBC			Tim	2	5	
10	Tim McCarthy	Spaceborne	Copernicus 10m DEM - Global and European Digital Elevation Model (COP-DEM)	https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1	ESA	2010- 2015?	Paul	0.25	0.25	
12	TBC	Instrument	Carnsore Point		EPA	2005	Paul	0.5	1	
13	TBC	Instrument	Malin Head		EPA / ME		Paul	0.5	1	
14	TBC	Instrument	Valentia Observatory		Met Eireann		Paul	0.5	1	
15	TBC	Online	Weather Stations Country Wide		Met Eireann		Paul	1	2	
16	TBC	Instrument	Mace Head		NUIG		Tim	0.5	1	
17	Garry Langan	Instrument	Johnstown Castle/Grass (Operational)		Teagasc	2005-2021	Tim	0.5	1	
18	Garry Langan	Instrument	Castledockrell Crop (Operational)		Teagasc	2021 -				
19	Garry Langan	Instrument	Castledockrell Grass (Operational)		Teagasc	2021 -				
20	Garry Langan	Instrument	Ballycaneew (Operational)		Teagasc	2021 -				
21	Garry Langan	Instrument	Timoleague (Operational)		Teagasc	2021 -				
22	Garry Langan	Instrument	Lyons Farm (Pending Approval)		Teagasc	Q2 2021				
23	Garry Langan	Instrument	Curtins Farm, Fermoy (Pending expected to be Operational soon)		Teagasc	Q2 2021				
24	Garry Langan	Instrument	Moorepark (Vistamilk tower?) (need to check)		Teagasc					
25	Garry Langan	Instrument	North Laois/South Offaly EP (Pending)		Teagasc	Q2 2021				
26	Garry Langan	Instrument	Solohead Grass/Clover (Old Data)		Teagasc	2011-14				
27	Matt Saunders	Instrument	All Saints (Re-hab)							
28	Matt Saunders	Instrument	Clara/Peatland (near natural) (Operational)		TCD	2018 onwards				
29	Matt Saunders	Instrument	Cavernmount/Peatland (extraction rehabilitation) (Operational)		TCD	2021-onwards				
30	Rowan Fealy	Instrument	Burishoole (not-Operational - proposed as monitored catchment)							
31	Rowan Fealy	Instrument	Killorglin/Peatland - Old UCC		Fluxnet	2002-12	Tim	0.5	1	
32		Instrument	Killorglin/Peatland - Old UCC - T-AI may re-establish?		T-AI					
33		Instrument	Natural forest (site to be determined) - Ken/Brian/Matt		T-AI					
34		Instrument	Coniferous (site to be determined) - Ken/Brian/Matt		T-AI					
35	Rowan Fealy	Instrument	Dripsey/Grass - Old UCC		Fluxnet	2002-13	Tim	0.5	1	
36	Rowan Fealy	Instrument	Johnstown Castle/Grass - Old UCC		Fluxnet		Tim	0.5	1	
37	Rowan Fealy	Instrument	Dooary/Forest - Old UCC		Fluxnet		Tim	0.5	1	
38	Rowan Fealy	Instrument	Dooary/Forest - Old UCC - Brian re-establish?		UCC					
39	Rowan Fealy	Instrument	Carlow/Grass - Old UCC		Fluxnet	2002-2011?	Tim	0.5	1	
40	Rowan Fealy	Instrument	Carlow/Crop - Old UCC		Fluxnet	2004-2008	Tim	0.5	1	
41	Rowan Fealy	National	MERA				Paul	1	2	
42	Rowan Fealy	National	ERDDAP				Paul	1	2	
44	Rowan Fealy	Global	ERAS (atmosphere)	https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-eras	ECMWF	1981-present				
45	Rowan Fealy	Global	ERAS (land)	https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-eras	ECMWF	1981-present				
46	Rowan Fealy	Europe	UERRA (Land)	https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-uerre-europe-soil-level		1961-2019				
49	Ken Byrne	National	National Forest Inventory	https://www.gov.ie/en/publication/65294-irelands-national-forest/	DAFM		Tim	0.5	1	
50	Ken Byrne	National	FIP95		DAFM		Tim	0.25	0.5	
51	Ken Byrne	National	FIP98		DAFM		Tim	0.25	0.5	
52	Ken Byrne	National	PrivateForests2016		DAFM		Tim	0.12	0.25	
53		National	LPIS		DAFM		Tim	0.5	1	

DC Themes

- Atmosphere
- Weather
- Environment
- Hydrology
- Land Surface & Mgt
- Soil
- Geology
- DEM/DSM
- GIS
- Human-Activity

Metadata Standards

- Irish Spatial Data Exchange
- Irish Spatial Data Infrastructure
- INSPIRE, FGDC, ISO19139, OGC
- also LULUCF EAGLE

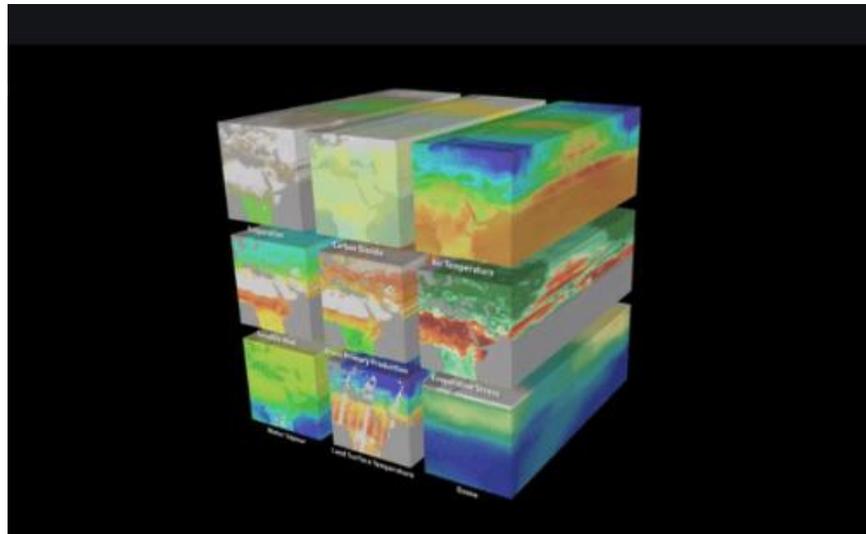
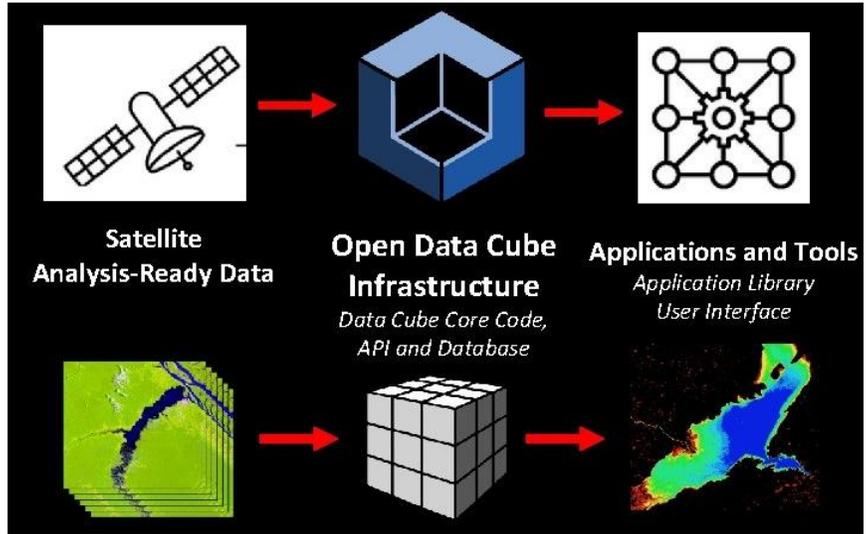
Current T-AI DC

- Approx. 100 - 120 datasets, data-Streams, APIs, & DataBases

Data Privacy & Licensing

- Data Management Plan, Robust Protocols for Data Privacy
- Support for Open Access & Open Data

Terrain-AI: Data Cube



Storage & Discovery

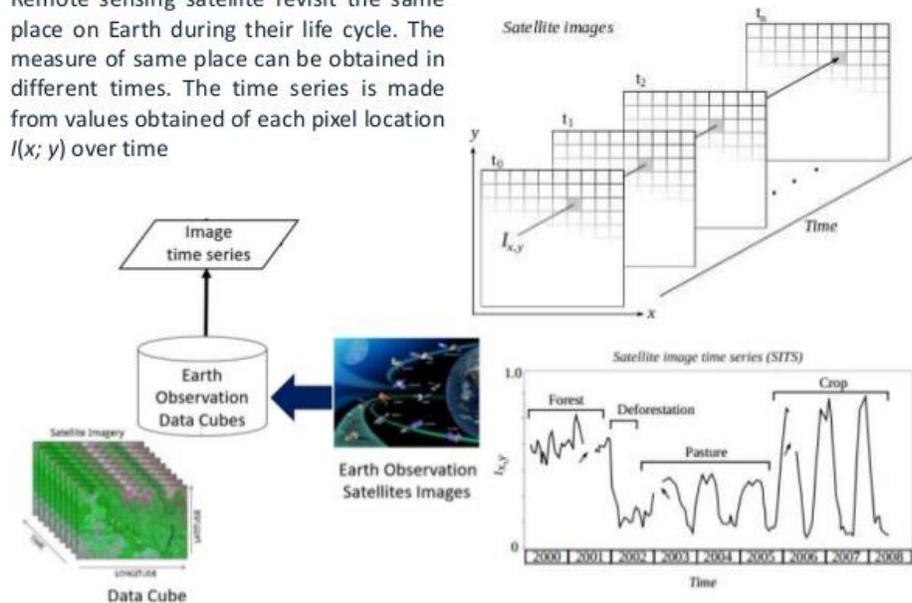
- Petabyte Scale EO/GEO
- Data Indexing/Metadata
- Cloud-free imagery

Analysis & Modelling

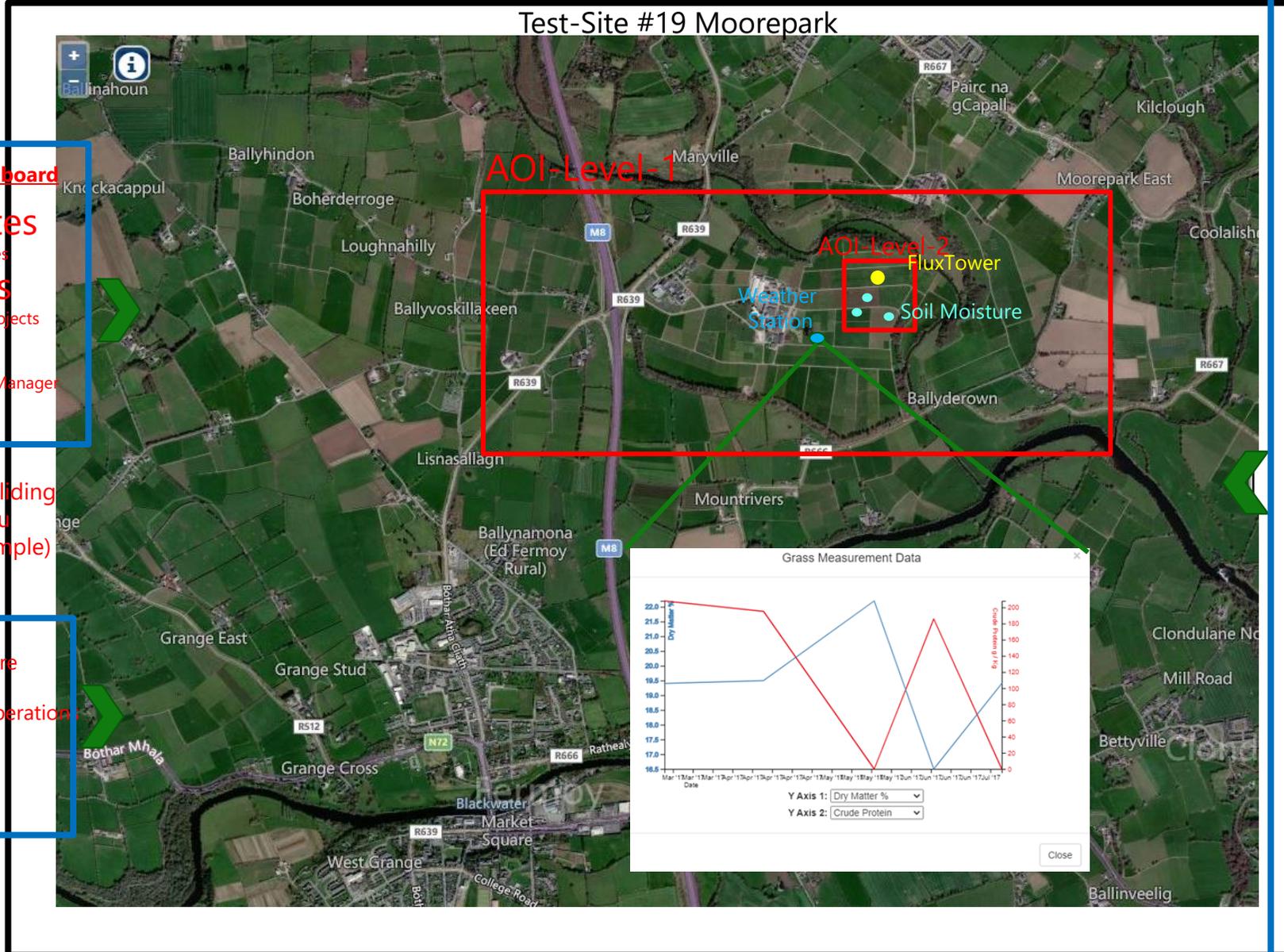
- Fusion & Analysis (Temporal, Spatial, Spatial, Multimodal)
- Indices (NDVI, NDBI, NDWI, SAVI, EVI)
- Land Classification (K-means, RF)
- Time-series
- Integrated Earth System

Earth Observation Data Cube

Remote sensing satellite revisit the same place on Earth during their life cycle. The measure of same place can be obtained in different times. The time series is made from values obtained of each pixel location $I(x; y)$ over time



Terrain-AI: Data Platform Dashboard



- 8. T-AI Dashboard**
- Test-Sites**
-list/map of sites
 - Projects**
-list/map of projects
 - Team**
-display Team Manager

2a. Sliding Menu (example)

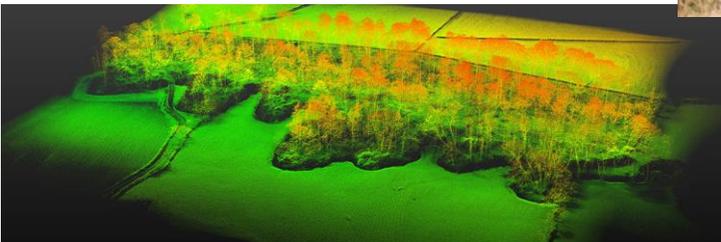
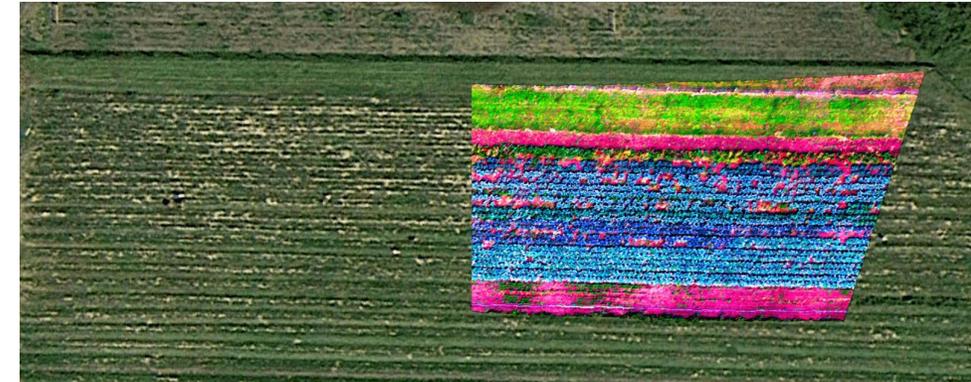
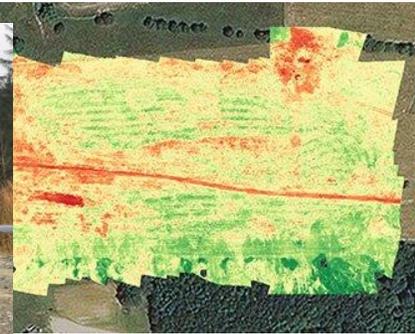
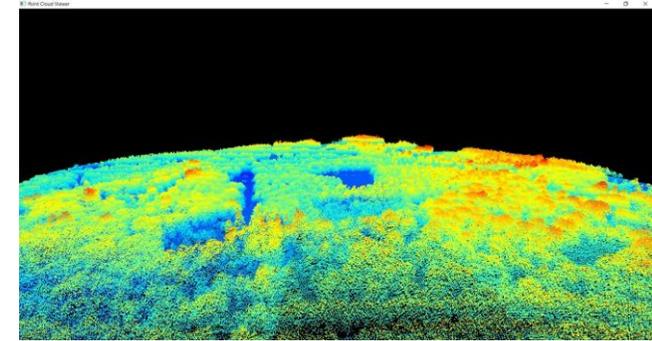
- 7. Map Tool**
- Digitise Feature
 - Measure Tool
 - Geospatial Operations
- Analysis Tools
 - Extract
 - Overlay
 - Proximity
 - Buffer

3. Layer Manager - Cascading)

- Remote Sensing**
- Spaceborne
 - Sentinel-1
 - Sentinel-2
 - Sentinel-2-date-1
 - RGB Composite
 - NDVI
 - Sentinel-2-date-2
 - Airborne
 - RGB Photogrammetry
 - DSM (legend) - grid
 - Multispectral
 - LIDAR
 - Drone
 - RGB Photogrammetry
 - LIDAR
 - Hyperspectral
 - Thermal
- In-Situ Instruments**
- Weather Station
 - Flux Tower
 - Chamber
 - Spoil Moisture
- Land Surface**
- Forestry NFI
 - Lucas
 - 2018
 - 2017
 - CORINE
 - 2018 (Legend)
 - 2012 (Legend)
 - Biomass
- Soils**
- Soil Map (Legend)
 - Soil Survey (10 X points)
- DEM**
- 10m Copernicus
 - Photogrammetry DEM
- GIS**
- AOI
 - Level-1
 - Level-2
 - Field Boundaries
 - Infrastructure
 - Demography
 - User Defined Data
- Base Layer**
- Bing Satellite
- Test-Site Details**
- Full description of test-site (Owner, Sensors, Activity etc)

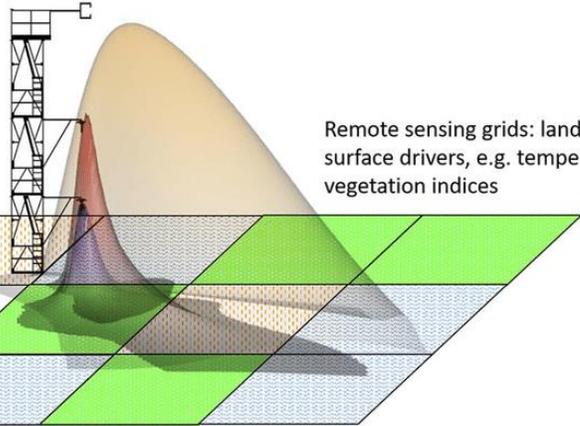
Discovery – Visualisation - Sharing

Terrain-AI: Remote Sensing Platforms & Sensors



Terrain-AI: Field Instruments & In-Situ Sensors

Tower measurements: flux responses; meteorological drivers, e.g. temperature, humidity

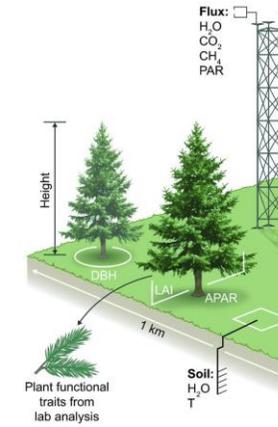


Remote sensing grids: land surface drivers, e.g. temperature, vegetation indices



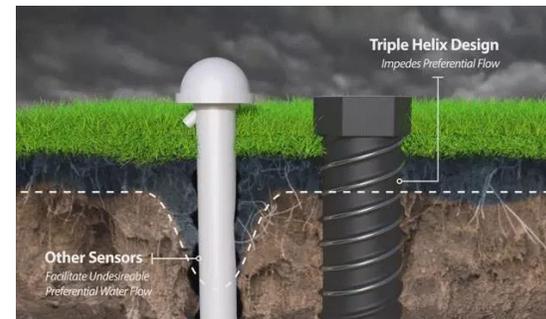
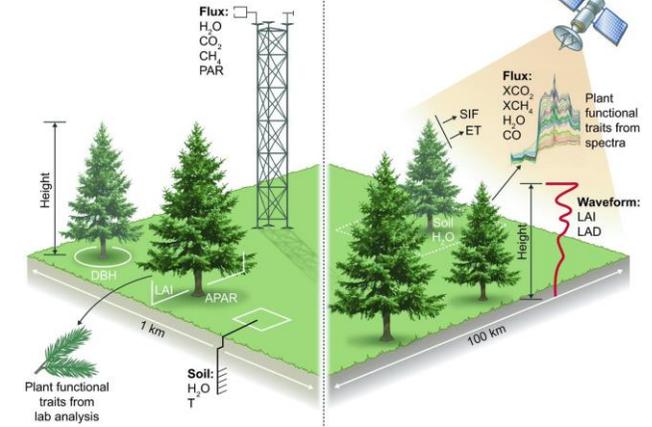
In situ

Carbon equation
 $GPP = NEE_{EC} - R_{ECO} \text{ (night)}$



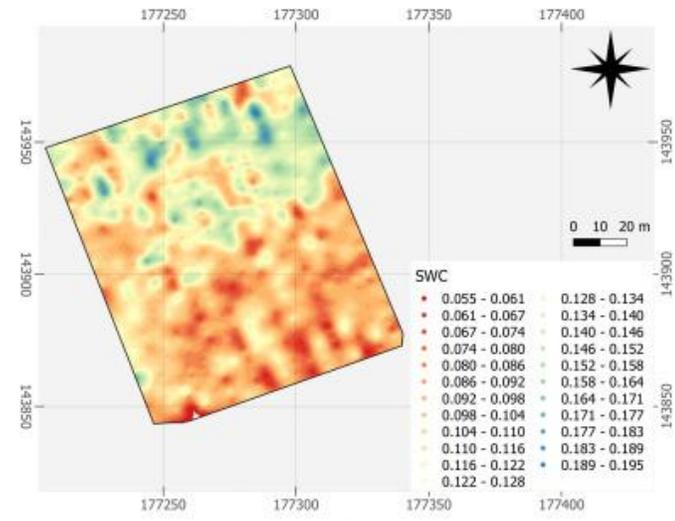
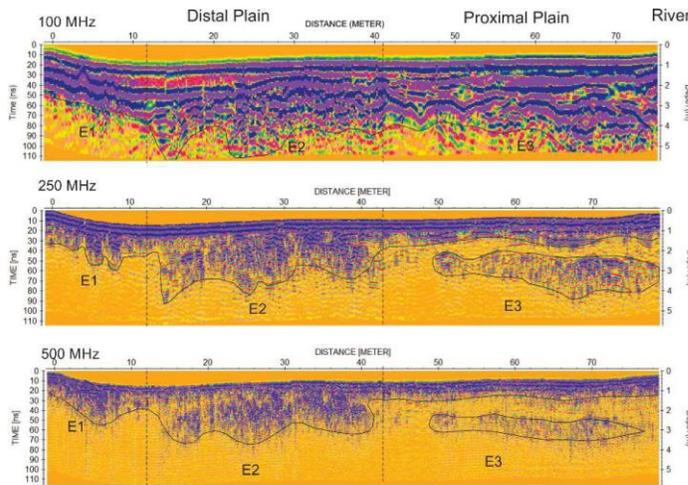
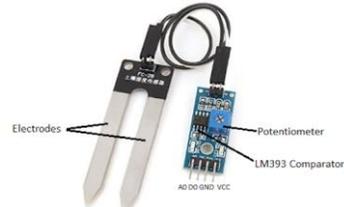
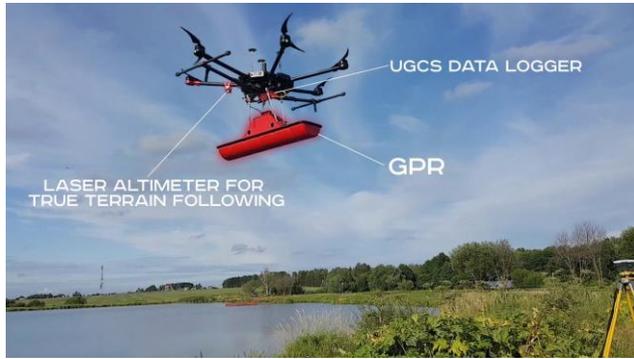
Space

Carbon equation
 $R_{ECO} = NEE_{XCO_2} - GPP_{SIF} - Fire_{CO}$



Drone GPR

- Soil Texture
- Soil Structure
- Soil Series
- Bulk Density
- SWC



SWC

• 0.055 - 0.061	• 0.128 - 0.134
• 0.061 - 0.067	• 0.134 - 0.140
• 0.067 - 0.074	• 0.140 - 0.146
• 0.074 - 0.080	• 0.146 - 0.152
• 0.080 - 0.086	• 0.152 - 0.158
• 0.086 - 0.092	• 0.158 - 0.164
• 0.092 - 0.098	• 0.164 - 0.171
• 0.098 - 0.104	• 0.171 - 0.177
• 0.104 - 0.110	• 0.177 - 0.183
• 0.110 - 0.116	• 0.183 - 0.189
• 0.116 - 0.122	• 0.189 - 0.195
• 0.122 - 0.128	

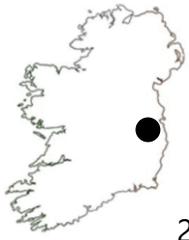
Drone Gas Sniffers



Intelligent Flying Air Quality Monitoring Laboratory

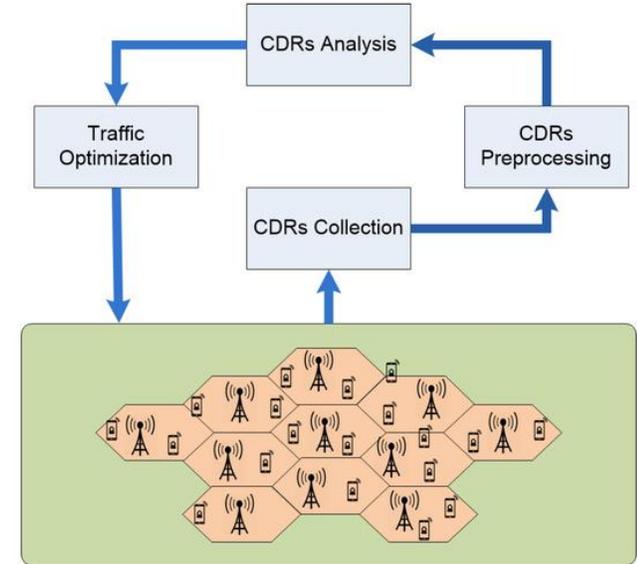
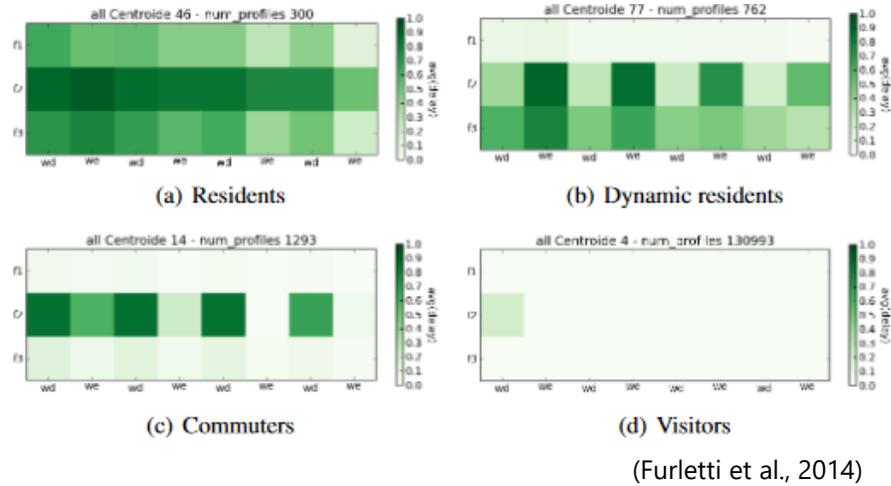
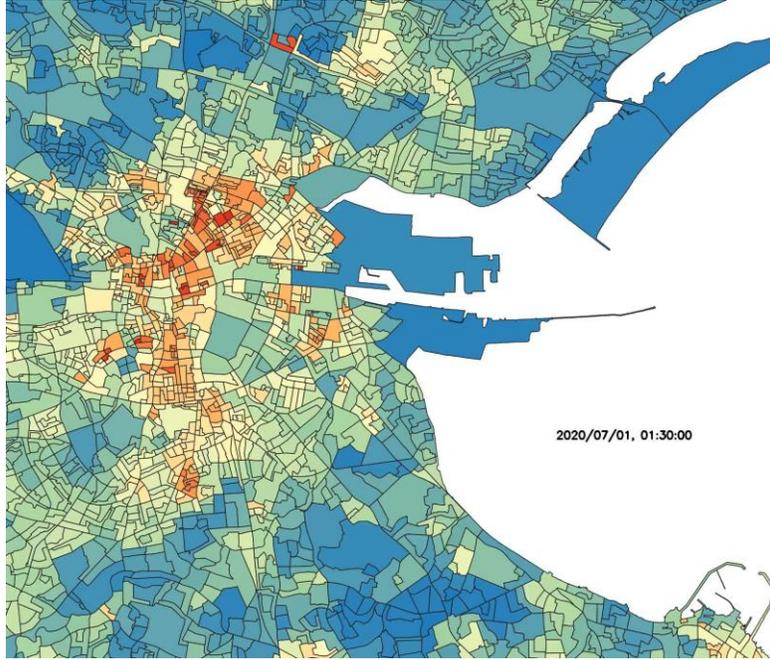
Measures gases using a series of sensors selected based on application. With a library of over 50 sensors, 4 Electrochemical, 1 NDIR sensor (CO₂), 1 PID sensor (VOC), 1 MOS, and PM 1, PM 2.5, PM 4 and PM 10

- Volatile organic compound sensing using photo-ionization technology
- CO₂, CH₄, NO_x, SO_x using a non-dispersive infrared sensor
- Sensing capabilities for particulates **PM 1, PM 2.5, and PM 10**
- **Total Reduced Sulfurs** (or TRS), along with other contaminants using our Metal Oxide technology
- Temperature, humidity, and barometric pressure
- High accuracy GPS recording
- High accuracy altitude measurements

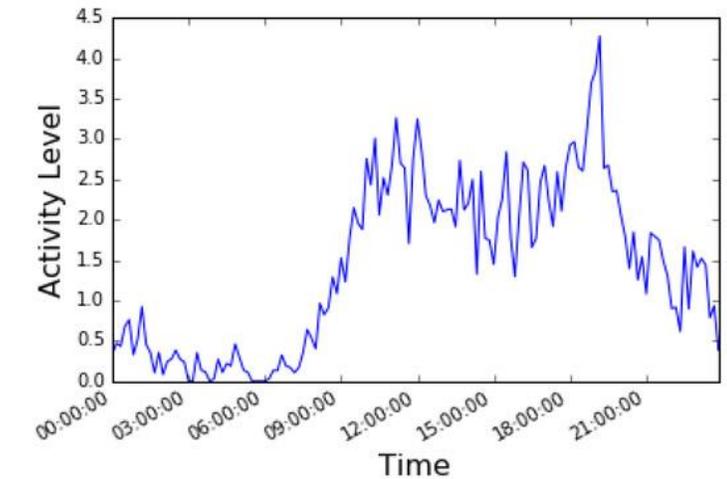
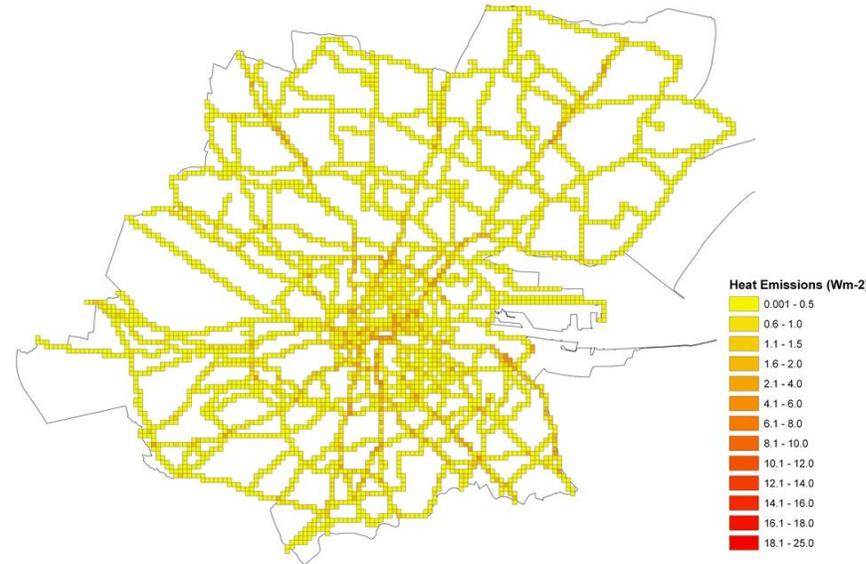


GDPR-compliant Mobile-phone data / Human Activity Data

24-hr (hourly) Occupancy-Flow

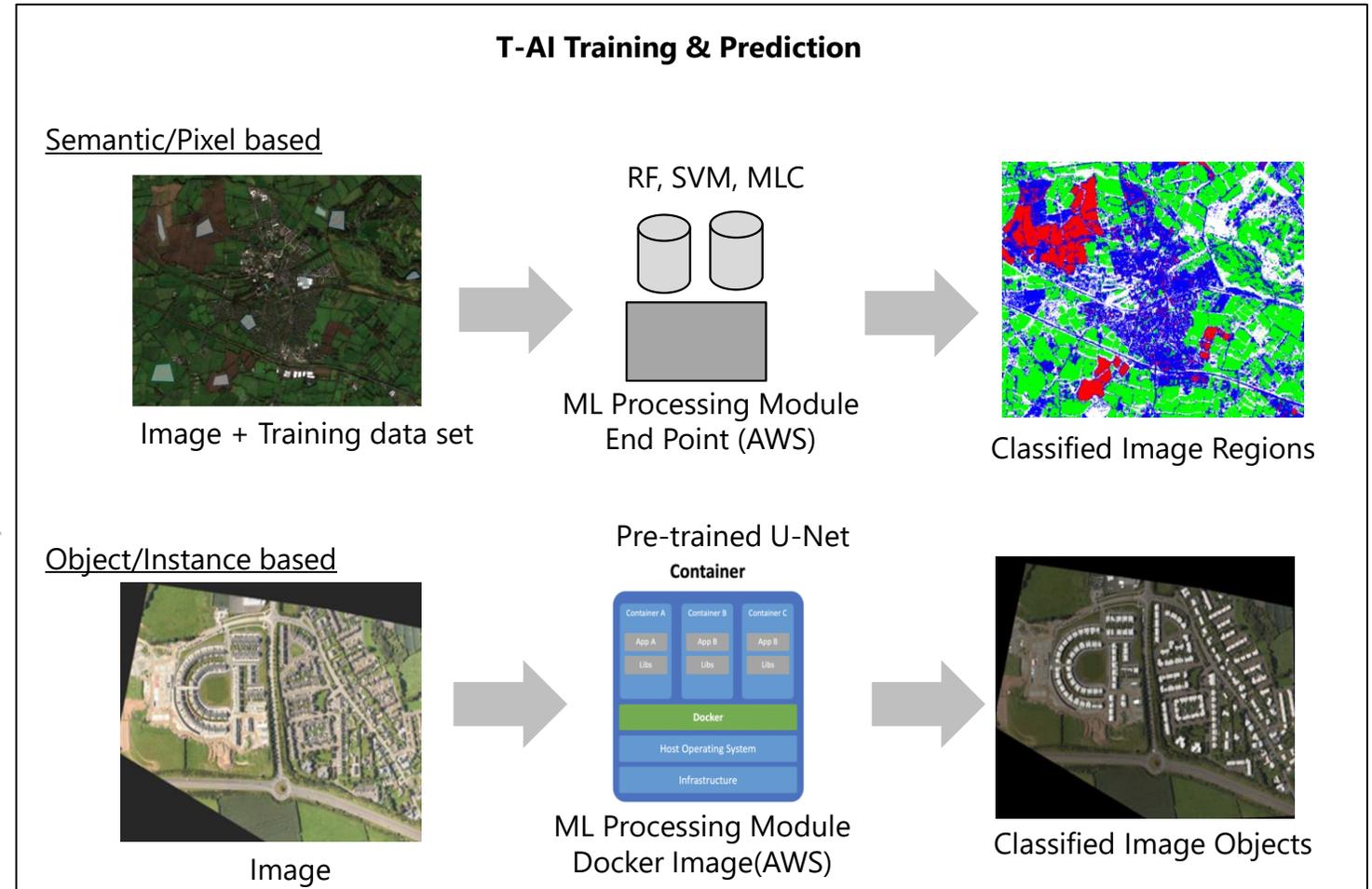


Origin-Destination



(Sultan et al., 2019)

T-AI Data Platform: Machine Learning Pipeline



Residential



Urban Profiling

Energy Conservation

- Residential Unit Classification
- Building classification – insulation
- Roof Profiling : Shape, Area, Material, Pitch

Environment, Health & Well being

- Green spaces/Trees
- Air Quality Noise
- Access to Light

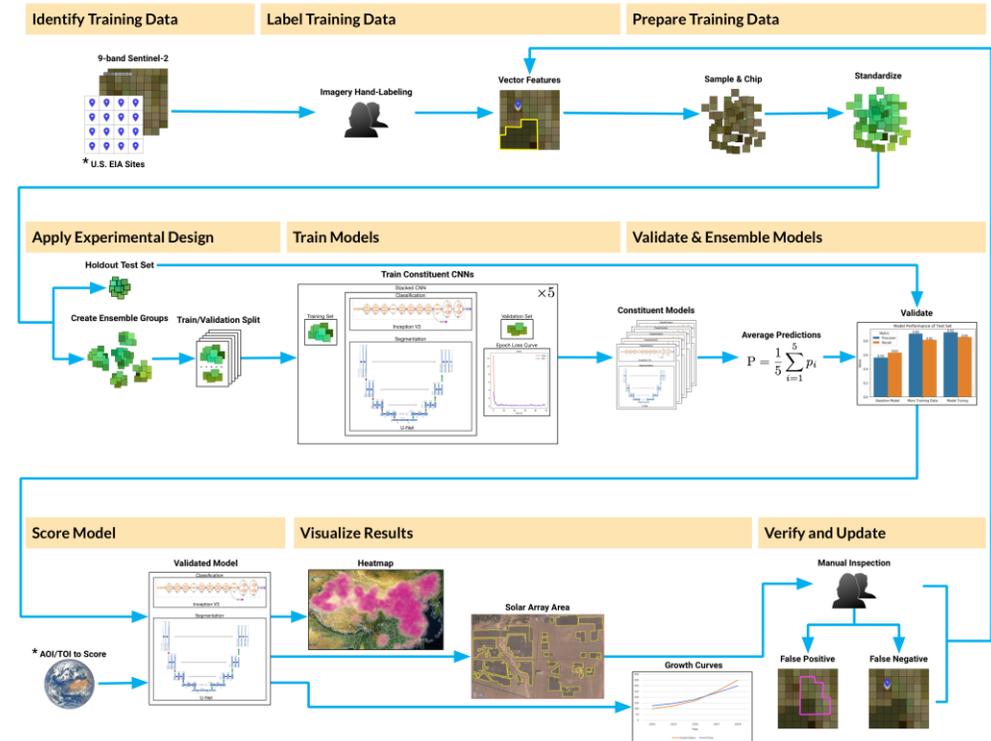
Transportation

- Public Transportation
- Personal Transport
- Driveway & On-street Car-Parking

15-minute City Bubble Categorisation

- Services, Occupancy & Flow

ML Pipeline for Building Classification



T-AI Data Platform – Decision Support for Carbon Management

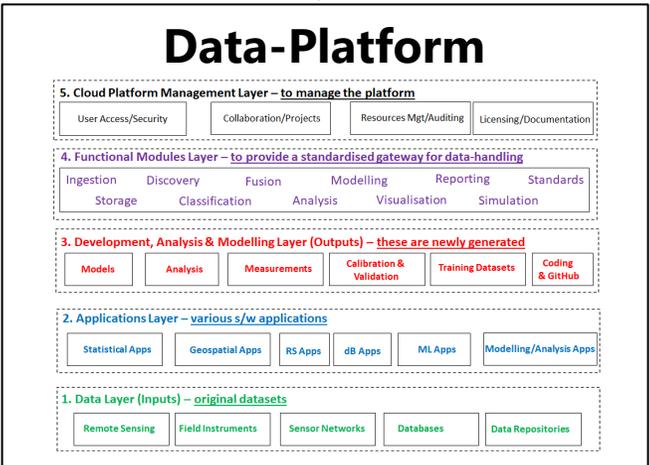
Data & Information Services

- EO Data Products • ML Training Datasets & Pipelines
- Biomass/Quality/Yield Metrics • Habitat Management Metrics
- Integrated Earth System Models • Simulation

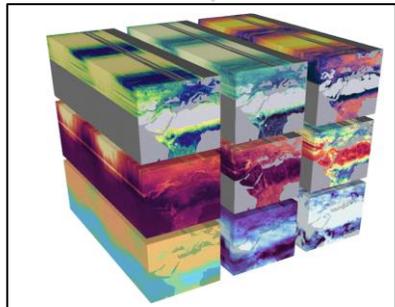
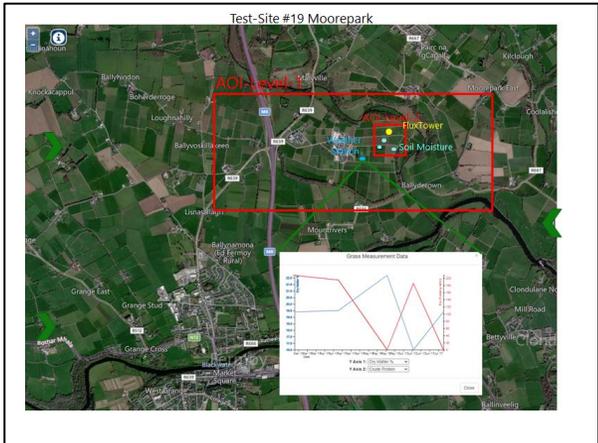


Data Catalogue

Name	URL (or Meta-Information)	Provider	Year	File Size	View/Download
...



Dashboard



DataCube