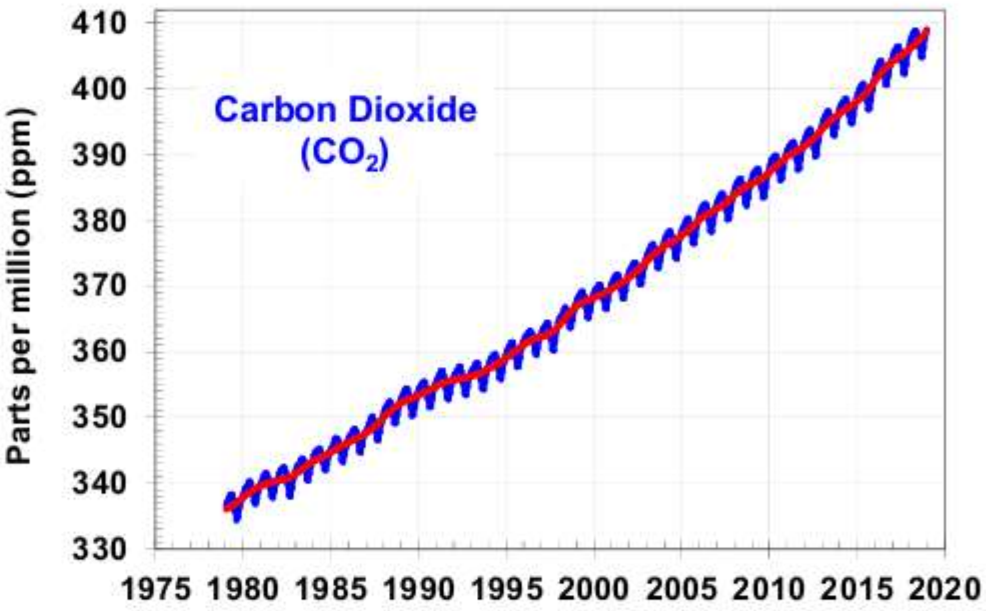
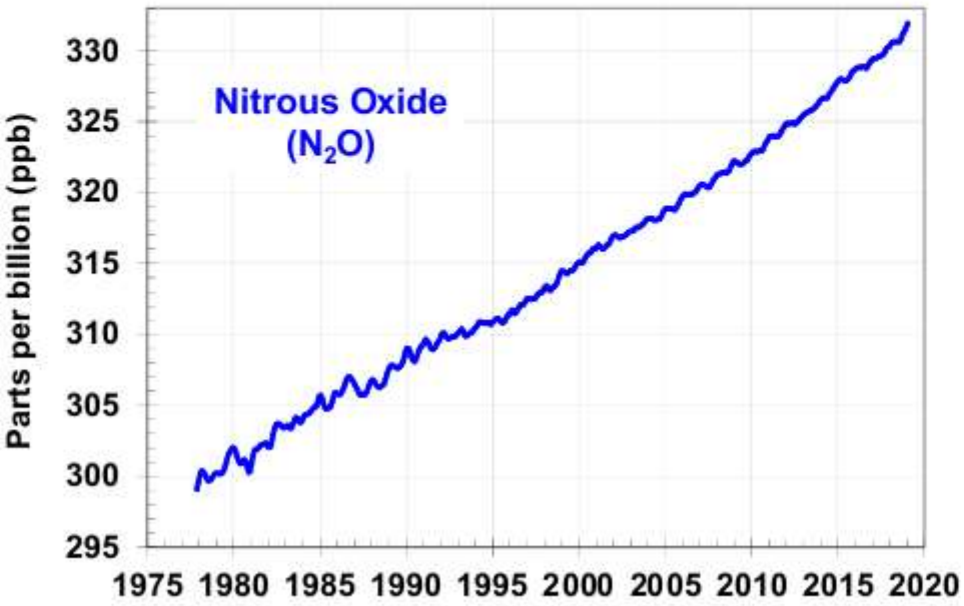
Measurement of GHGs
CO_2, N_2O and CH_4

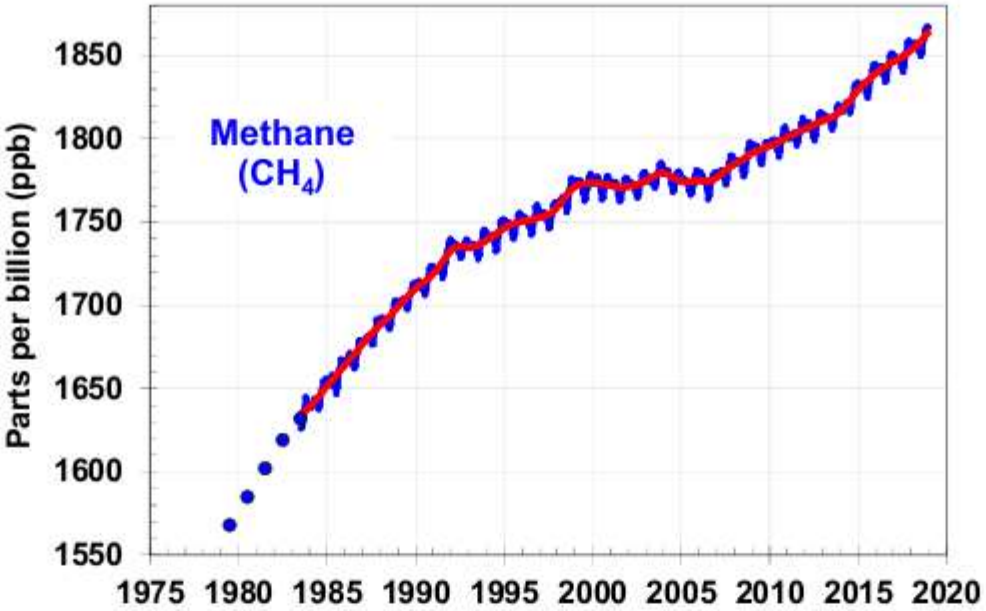
Suman George

Murdoch University

AEGIS (Action on Emission of GHGs for Integrated Sustainability) Research Consortium







WORLD
METEOROLOGICAL
ORGANIZATION

26 October 2022 (WMO) - In yet another ominous climate change warning, atmospheric levels of the three main greenhouse gases - carbon dioxide, methane and nitrous oxide all reached new record highs in 2021,

GREENHOUSE GASSES

C02
CARBON DIOXIDE

The primary greenhouse gas, responsible for about three-quarters of emissions

CH4
METHANE

Accounts for about 16% of all greenhouse gas emissions

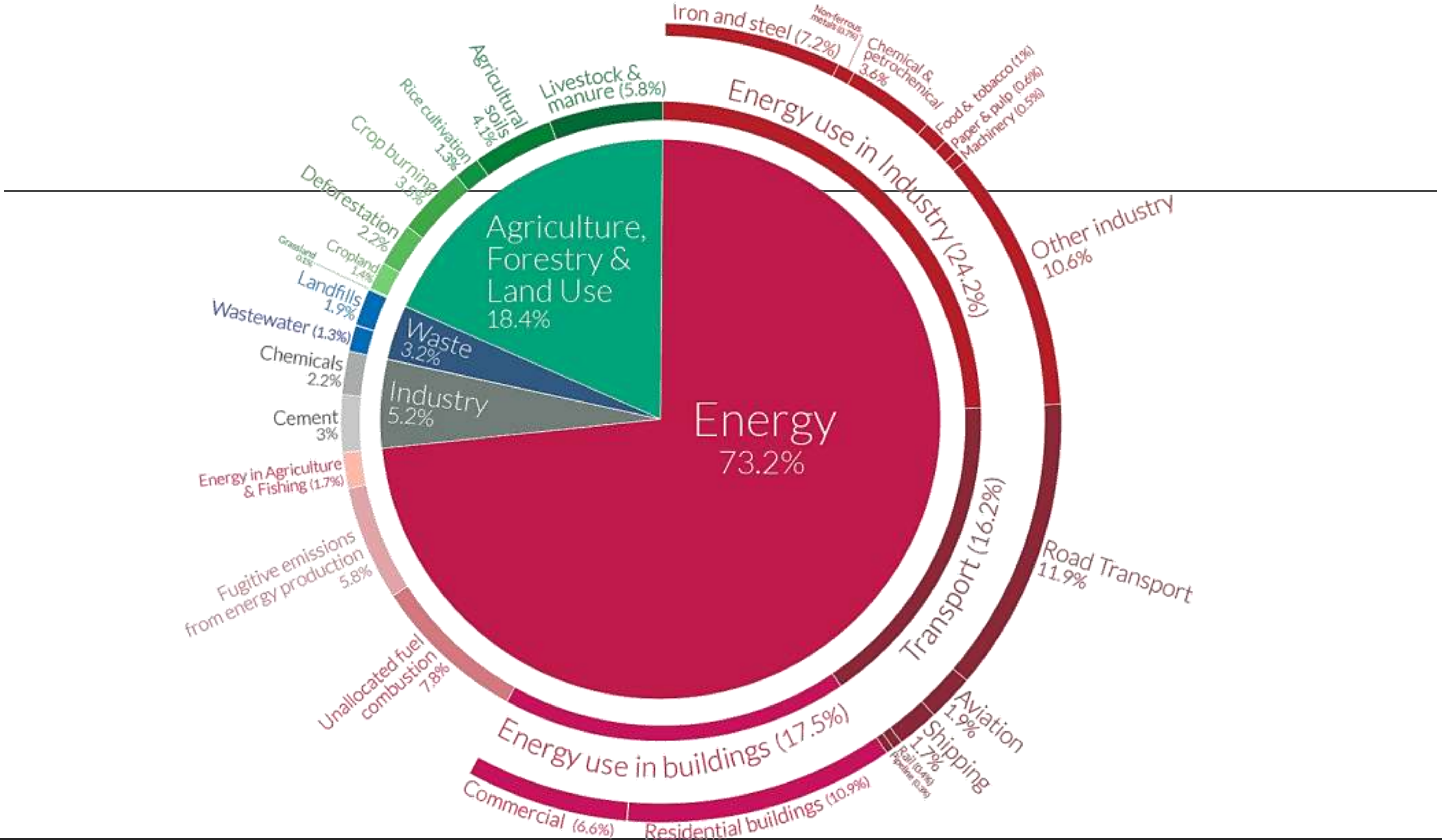
N20
NITROUS OXIDE

Accounts for only 6% of all greenhouse gas emissions but it is 264 times more powerful than carbon dioxide

Global greenhouse gas emissions by sector

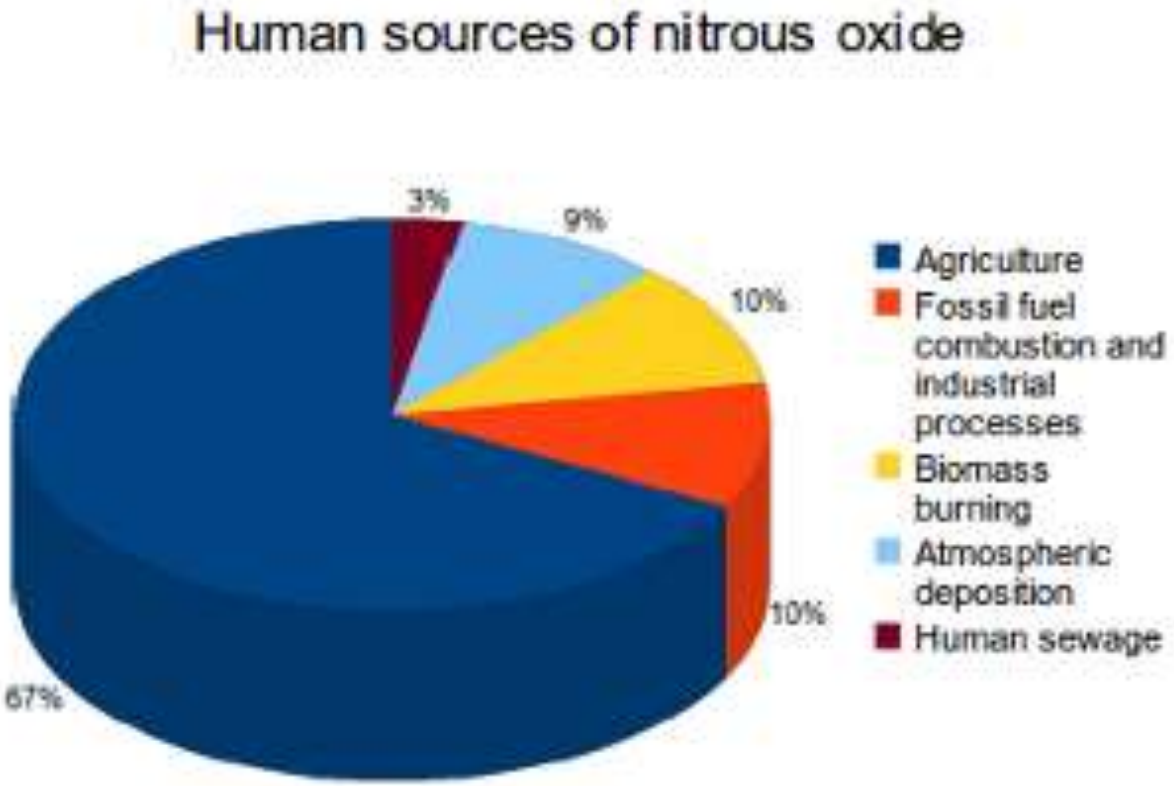
This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO_2eq.

Our World in Data

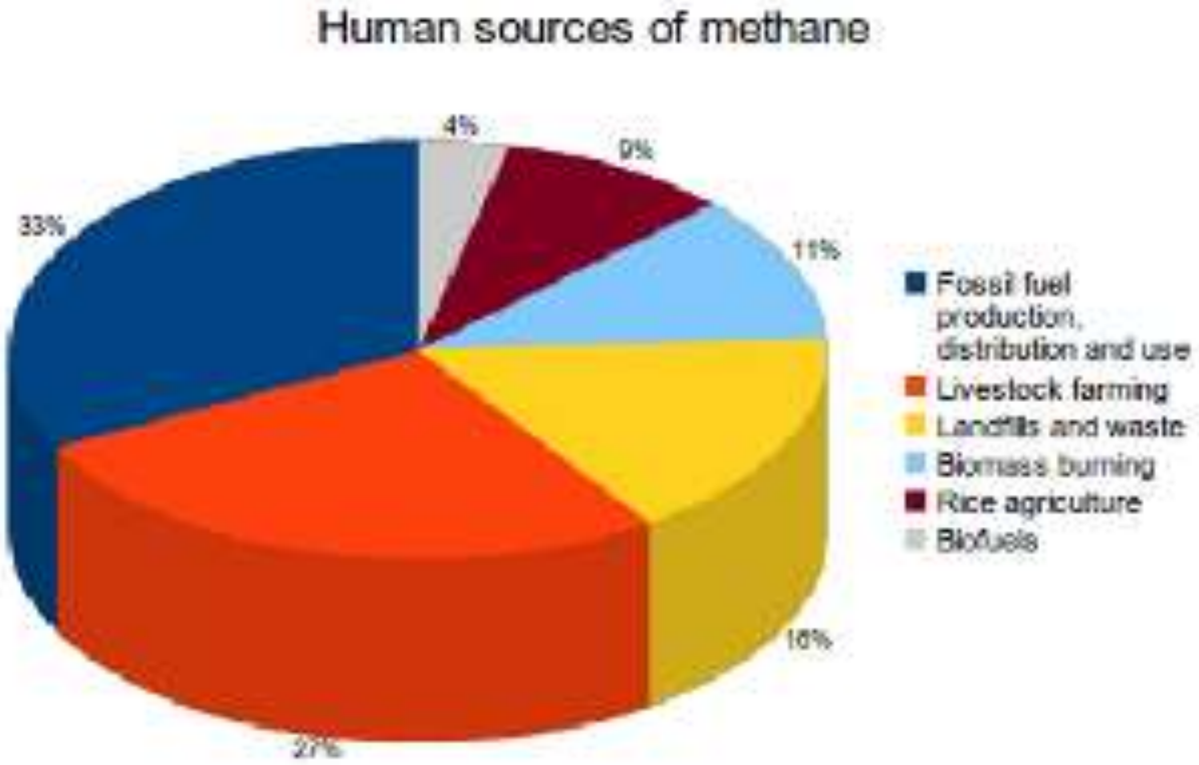


OurWorldInData.org – Research and data to make progress against the world's largest problems.

Source: Climate Watch, the World Resources Institute (2020).



Human sources of nitrous oxide



Human sources of methane

UNFCCC RESOURCE GUIDE

MODULE 3: NATIONAL GREENHOUSE GAS INVENTORIES
FOR PREPARING THE NATIONAL COMMUNICATIONS OF NON-ANNEX I PARTIES

gas-by-gas basis and in units
of mass, estimates of anthropogenic emissions of carbon
dioxide (CO2), methane (CH4) and nitrous oxide (N2O)

N_2O emissions (direct & indirect)

- N_2O is produced naturally in soils through microbial processes of nitrification, denitrification
- Main controlling factor → N availability in the soil (depends on N inputs, including N released from mineralization of SOM)
- Direct & indirect emissions of N_2O from managed soils occur
- N inputs include: Synthetic and organic fertilizer & N mineralisation associated with land use and/or management change
- Direct N_2O emissions from mineral soils are estimated when SOM is lost through oxidation, due to land-use or land management changes and this loss is accompanied by a mineralisation of N (F_{SOM})
- Indirect N_2O emissions occur through 2 pathways: volatilisation & leaching/runoff. Under tier 1, only indirect N_2O emissions from N leached resulting from mineralization of SOM associated with land use/management changes

N_2O emissions (direct &)

$$N_2O - N_{emissions} = \boxed{F_{SOM}} \cdot \boxed{EF_1}$$ Equation 11.1

Activity Data

Emission Factor

TABLE 11.1 DEFAULT EMISSION FACTORS TO ESTIMATE DIRECT N_2O EMISSIONS FROM MANAGED SOILS		
Emission factor	Default value	Uncertainty range
EF_1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised from mineral soil as a result of loss of soil carbon [kg N_2O–N (kg $N)^{-1}$]	0.01	0.003 - 0.03
EF_{1FR} for flooded rice fields [kg N_2O–N (kg $N)^{-1}$]	0.003	0.000 - 0.006

$$F_{SOM} = \sum_{LU}\left[\left(\Delta C_{Mineral,LU} \cdot \frac{1}{R}\right) \cdot 1000\right]$$ Equation 11.8

F_{SOM}: The net annual amount of N mineralised in mineral soils as a result of loss of SOC associated with change in land use and/or management system of practices, kg N.

$\Delta C_{Mineral,LU}$: SOM oxidised in mineral soils as a consequence of land use and/or management change. This term is calculated by applying the methodology described in previous slides for estimating SOC changes, t C.

R: The C:N ratio of the soil organic matter

The IPCC default value is **15** for forest land/grassland conversion to cropland & **10** for management changes in cropland

- To convert kg of N_2O-N emissions into tonnes of N_2O emissions, the result of equation 11.1 needs to be multiplied by 44/28 and by 10^{-3}

N_2O emissions (direct & indirect)

$$N_2O-N = \underbrace{\boxed{F_{SOM} \cdot Frac_{LEACH(H)}}}_{\text{Activity Data}} \cdot \underbrace{\boxed{EF_5}}_{\text{Emission Factor}}$$

Equation 11.10

$N_2O_{(L)}-N$: Annual amount of N_2O-N produced from leaching and runoff of N released from SOM mineralized, as consequence of land use and/or management change, in regions where leaching/runoff occurs, kg N_2O-N yr^{-1}.
$Frac_{LEACH-(H)}$: Fraction of all N mineralised from SOC losses in mineral soils, associated with changes of land use and/or management change, that is leached and runoff, kg N (kg of N additions)$^{-1}$ (Table 11.3).
EF_5: emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N(kg N leached and runoff)$^{-1}$ (Table 11.3).

- ☐ Input data needed are AD, leaching fraction and EF
- ☐ F_{SOM} is the same calculated for direct N_2O emissions

Leaching fraction kg N (kg N additions or deposition by grazing animals)$^{-1}$	Used for	Value
$Frac_{LEACH-(H)}$	N losses by leaching / runoff for regions where soil water-holding capacity is exceeded	0.30

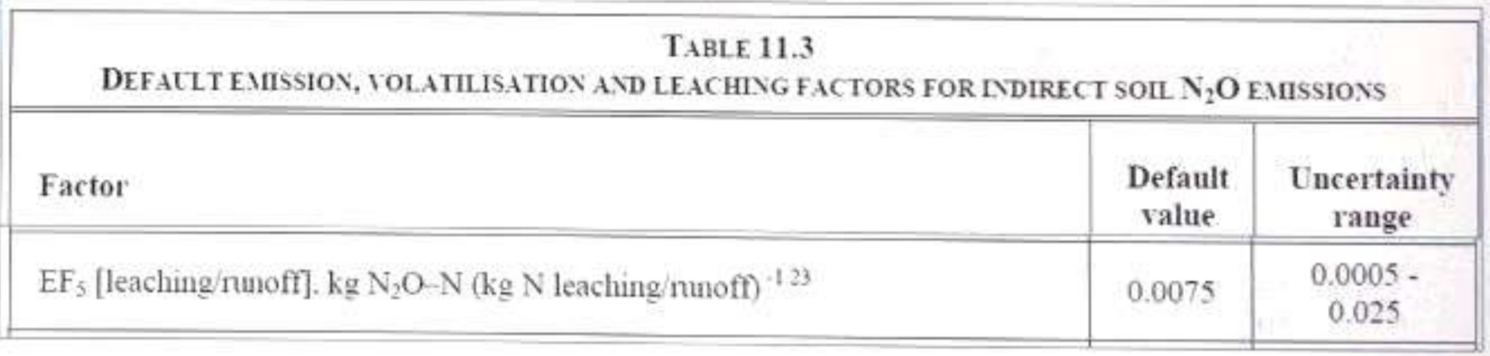


TABLE 11.3
DEFAULT EMISSION, VOLATILISATION AND LEACHING FACTORS FOR INDIRECT SOIL N_2O EMISSIONS

Factor	Default value	Uncertainty range
EF_5 [leaching/runoff], kg N_2O–N (kg N leaching/runoff)$^{-1}$ [23]	0.0075	0.0005 - 0.025

Source: 2006 IPCC Guidelines; FAO elearning academ
(the national GHG inventory for land use)

CH_4 emissions

- CH_4 emissions from mineral soils occur on Inland Wetland Mineral Soils (IWMS) that are rewetted (e.g., for cultivation of crops)
- Management activities that alter the water table on lands containing IWMS can impact CH_4 emissions
- IWMS are aquic soils (USDA) or gleysols (World Reference Base), having restricted drainage, leading to periodic flooding and anaerobic conditions
- Only 2013 IPCC Wetlands Supplement provides default methodology for estimating CH_4 emissions from IWMS
- Recall that CH_4 emissions from rice cultivations are reported under the agriculture sector
- IWMS might occur in any of the six land-use categories

Source: 2006 IPCC Guidelines; FAO elearning academ
(the national GHG inventory for land use)

CH_4 emissions

$$CH_{4-IWMS} = \sum_c \left(\boxed{A_{IWMS}} \times \boxed{EF_{CH_4-IWMS}} \right)_c$$

2013 IPCC Supplement on Wetlands, chapter 5, Equation 5.1

Activity Data Emission Factor

CH_{4-IWMS}: Annual CH_4 emissions from managed lands on IWMS where management activities have raised the water table level to or above the land surface, kg CH_4 yr^{-1}.
A_{IWMS}: Total area of managed lands with mineral soil where the water table level has been raised, ha.
EF_{CH_4-IWMS}: Emission factor from managed lands with mineral soil where water table level has been raised, kg CH_4 ha^{-1} yr^{-1} (Table 5.4 of 2013 IPCC Supplement on Wetlands).
c: Climate region.

Land representation

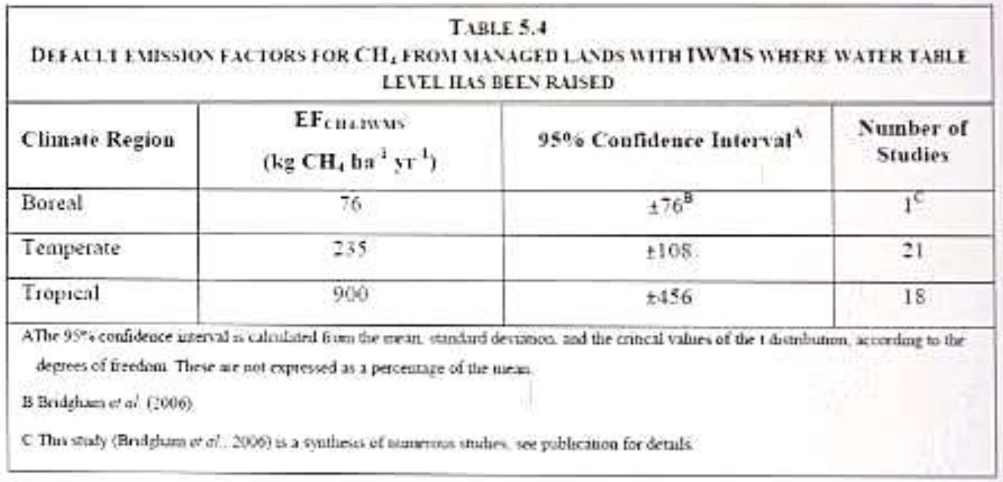


TABLE 5.4
DEFAULT EMISSION FACTORS FOR CH_4 FROM MANAGED LANDS WITH IWMS WHERE WATER TABLE LEVEL HAS BEEN RAISED

Climate Region	EF_{CH_4-IWMS} (kg CH_4 ha^{-1} yr^{-1})	95% Confidence Interval[A]	Number of Studies
Boreal	76	±76[B]	1[C]
Temperate	235	±108	21
Tropical	900	±456	18

A The 95% confidence interval is calculated from the mean, standard deviation, and the critical values of the t distribution, according to the degrees of freedom. These are not expressed as a percentage of the mean.

B Bridgham *et al.* (2006)

C This study (Bridgham *et al.*, 2006) is a synthesis of numerous studies, see publication for details.

- ❑ The area of managed lands with IWMS or dry mineral soil, where water table level has been raised, should be stratified by climate region

Source: 2006 IPCC Guidelines; FAO elearning academy (the national GHG inventory for land use)

IPCC OUTLINES A TIERED APPROACH FOR ESTIMATING GHG EMISSIONS

TIER 1

MULTIPLYING ACTIVITY DATA (AD) BY AN INTERNATIONAL DEFAULT FACTOR REPRESENTING EMISSIONS PER UNIT OF ACTIVITY

TIER 3

MORE DETAILED - FURTHER STRATIFICATION OF THE AD, AND EMISSION ESTIMATES, DIRECT MEASUREMENT, OR OTHER EQUIVALENT REGION-SPECIFIC APPROACHES.

TIER 2

APPROACHES GENERALLY INVOLVE THE APPLICATION OF A COUNTRY-SPECIFIC EMISSION FACTOR TO NATIONAL- OR REGIONAL-LEVEL AD;

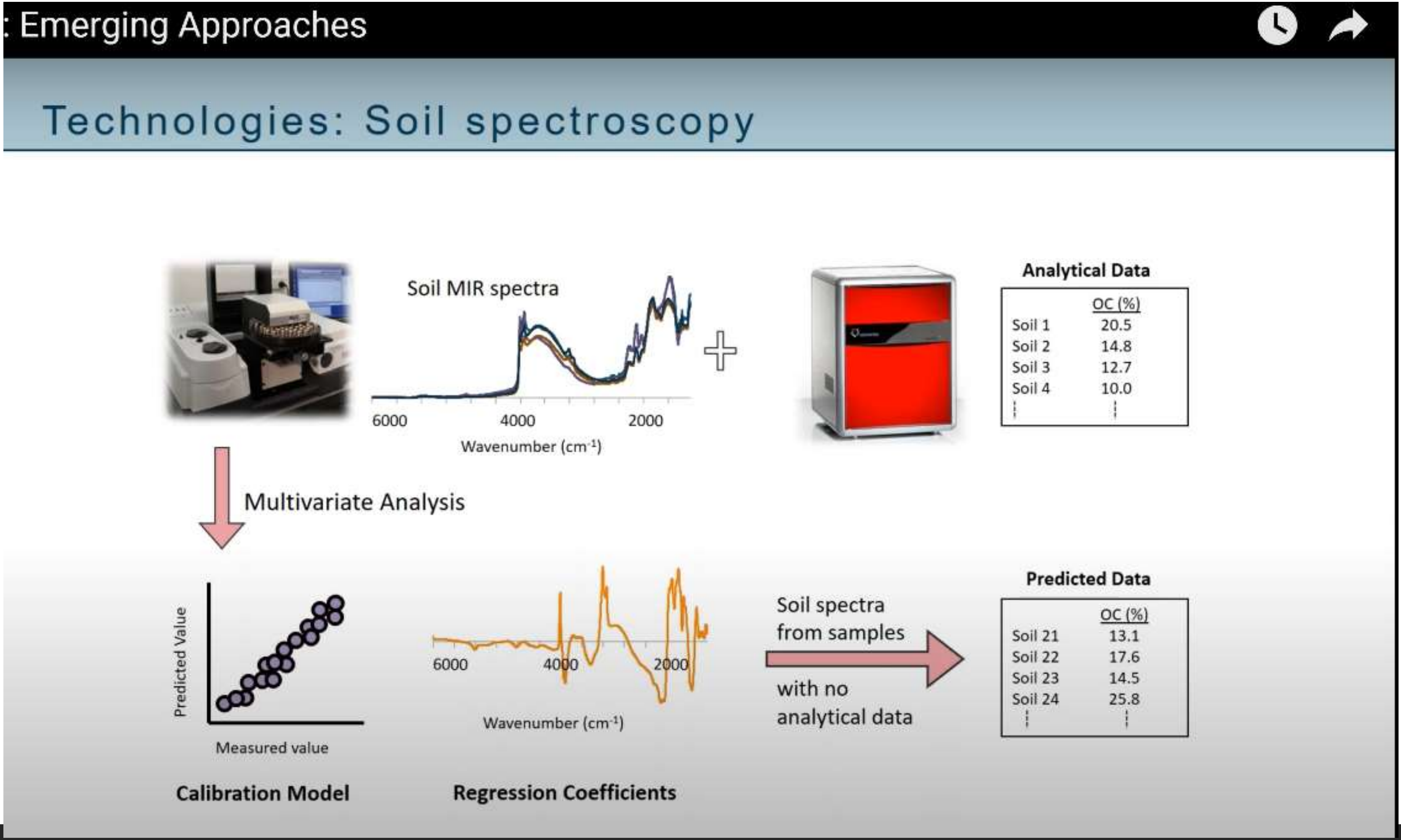
How to ground truth the modelled information

Tier one - Multiplying activity data by an international default factor representing emissions per unit of activity.

Use a Tier 3 level tool to ground truth will be obviously very different

With Tier 1 – we are trying to generate a base map when there is none with intention to progress towards higher Tiers

Even then we need to develop the capability to ground truth for carbon offsetting/carbon trading, helping in the transition to higher tiers, this is also an opportunity to improve the model.



: Emerging Approaches

Technologies: Soil spectroscopy

Analytical Data

	OC (%)
Soil 1	20.5
Soil 2	14.8
Soil 3	12.7
Soil 4	10.0
⋮	⋮

Calibration Model

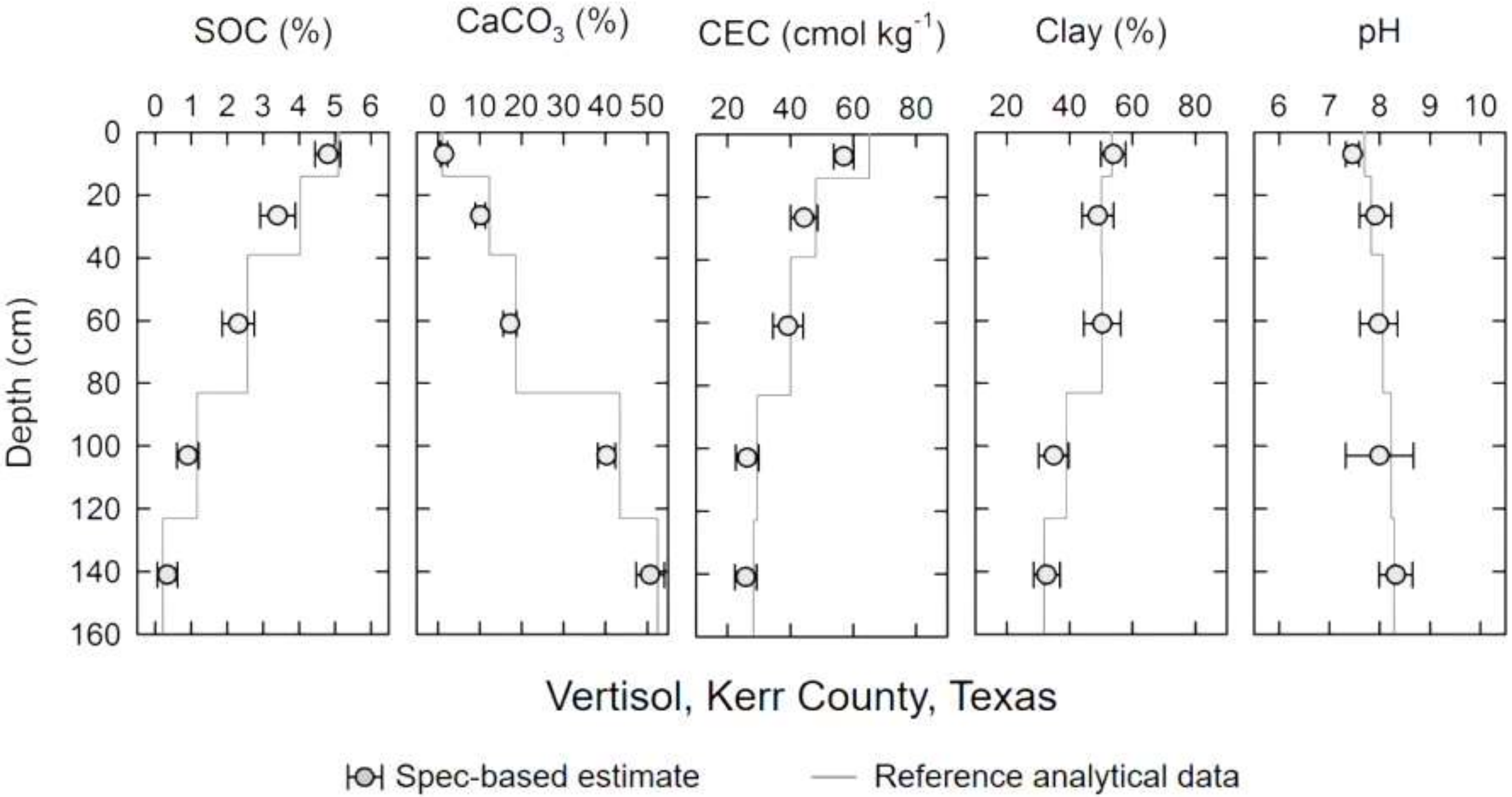
Regression Coefficients

Soil spectra from samples with no analytical data

Predicted Data

	OC (%)
Soil 21	13.1
Soil 22	17.6
Soil 23	14.5
Soil 24	25.8
⋮	⋮

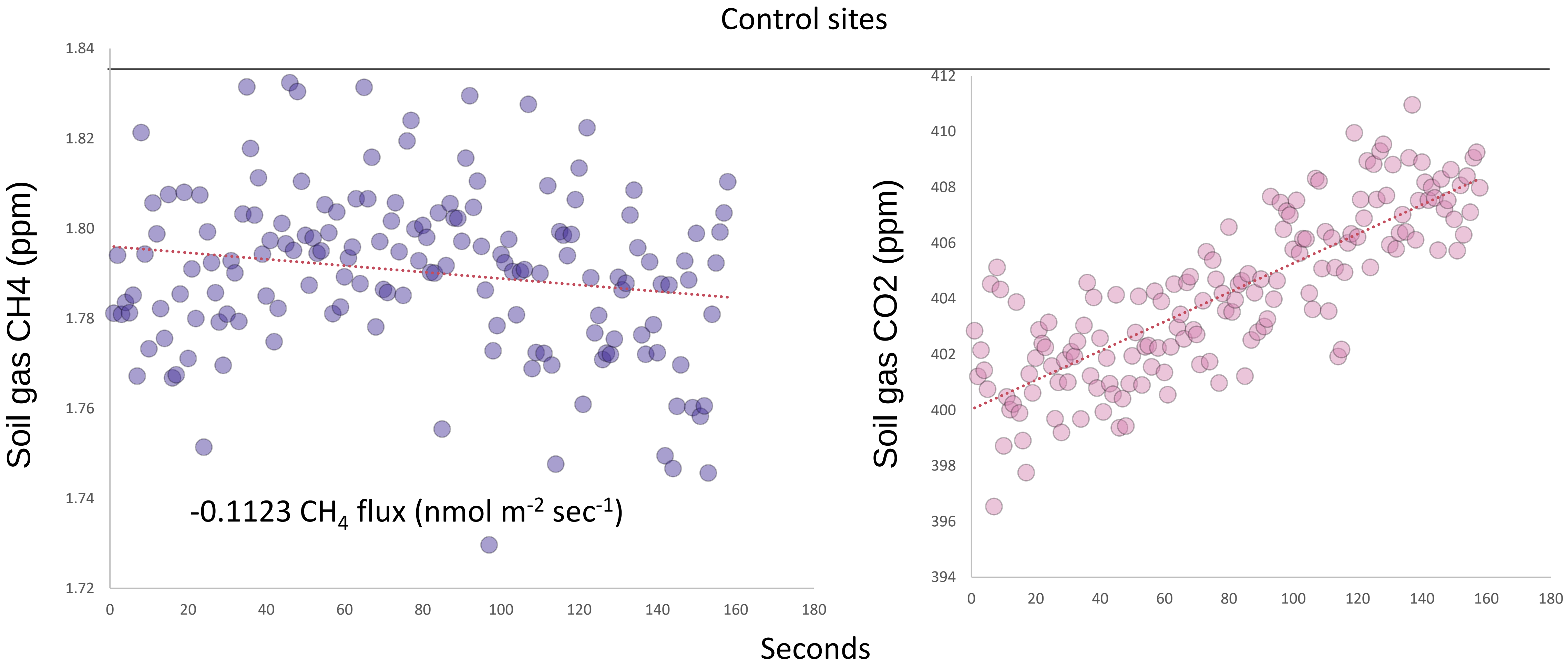
Technologies: Soil spectroscopy



Vertisol, Kerr County, Texas

Source: Sanderman et al. 2020 SSSAJ

Why Measure CO_2, N_2O and CH_4



-0.1123 CH_4 flux (nmol m^{-2} sec^{-1})

NEED OF THE HOUR:

TANDEM GHG MRV WITH IMPLEMENTATION OF CLIMATE-SMART MITIGATION PROJECTS IN AGRICULTURE

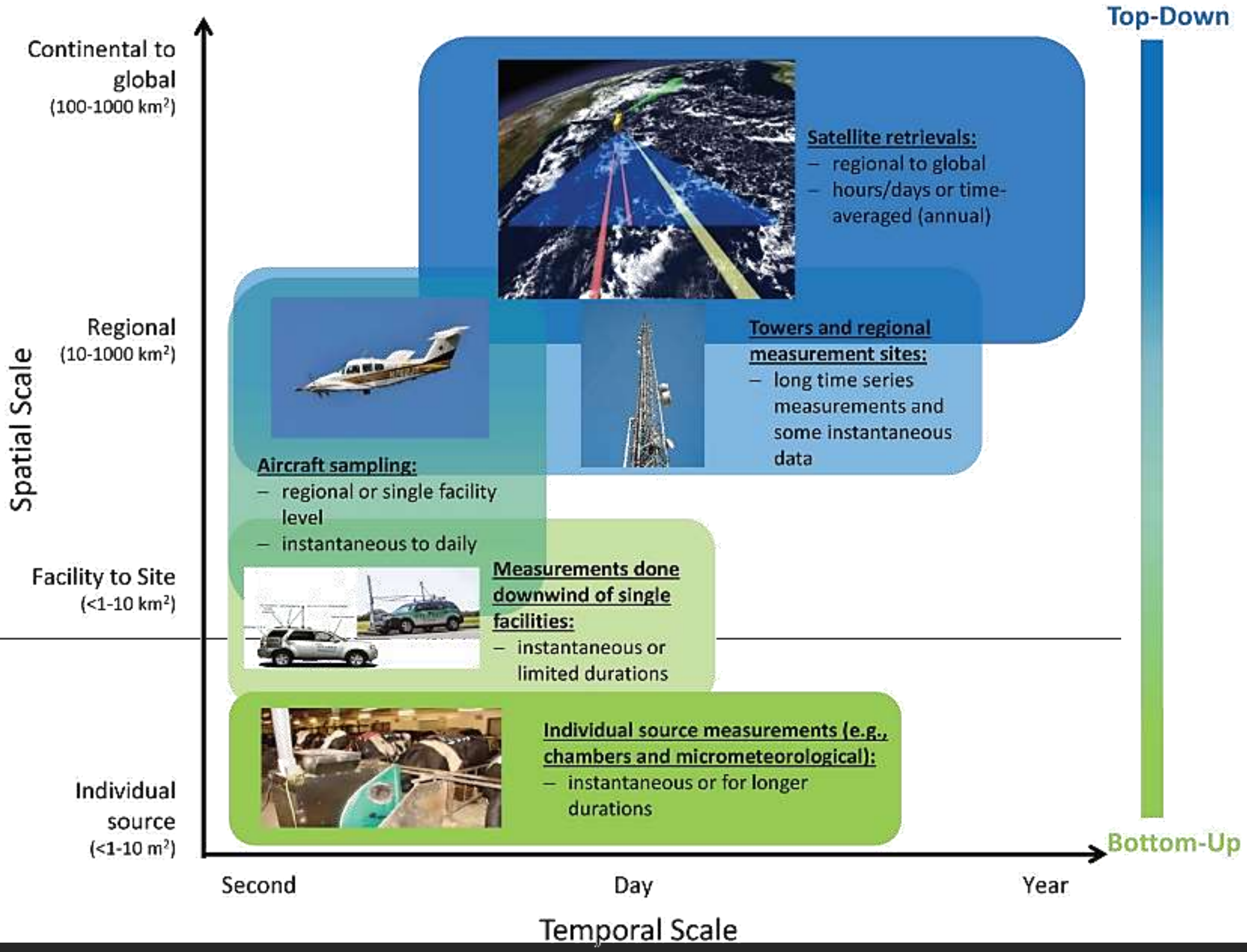
MONITORING CLIMATE MITIGATION/ADAPTATION TARGETS THROUGH THE LIFE OF A PROJECT

BIG PICTURE SCIENCE:

LEARNING FROM THE FEEDBACK LOOP

USUALLY DURING EXECUTION OF VARIOUS CLIMATE ADAPTATION/MITIGATION PROJECTS OPPORTUNITY FOR CONTINUOUS LEARNING AND R&D DEVELOPMENT IS MISSED.

MEASURING GHG IN A 4D SPACE



Satellite retrievals:
- regional to global
- hours/days or time-averaged (annual)

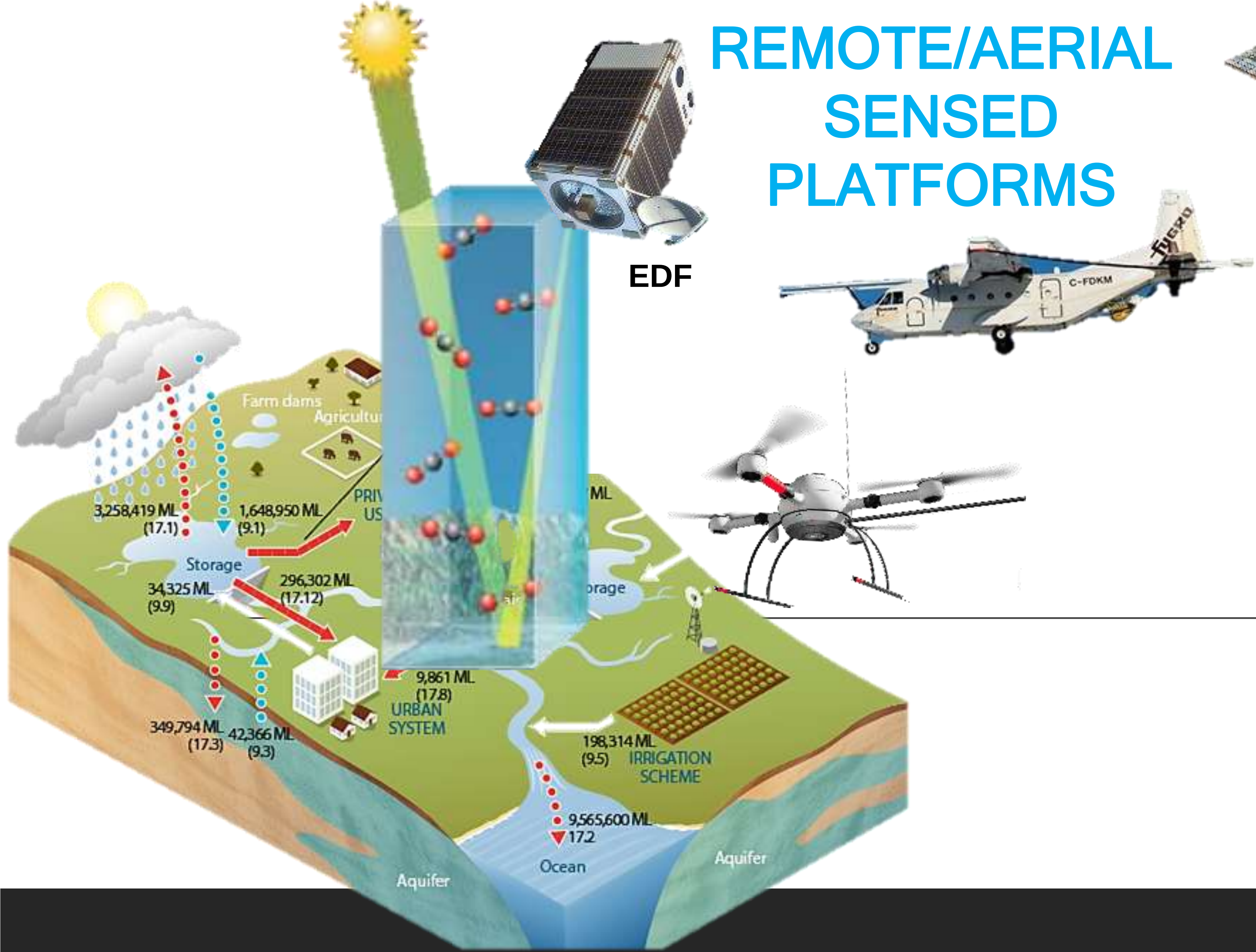
Towers and regional measurement sites:
- long time series measurements and some instantaneous data

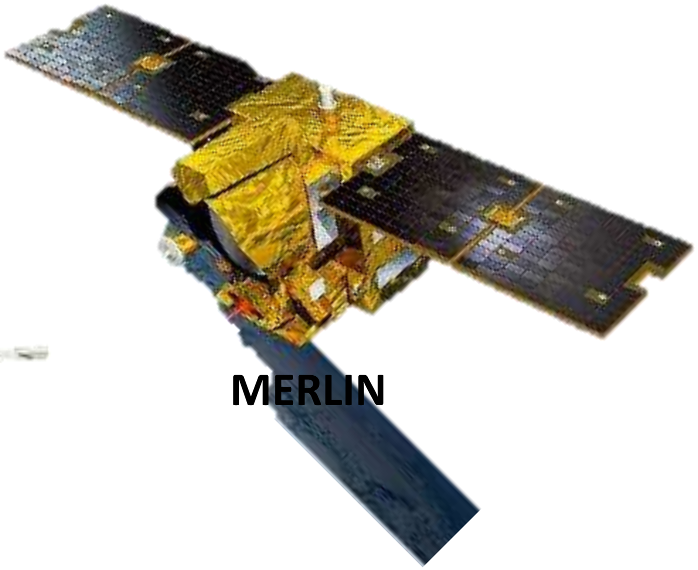
Aircraft sampling:
- regional or single facility level
- instantaneous to daily

Measurements done downwind of single facilities:
- instantaneous or limited durations

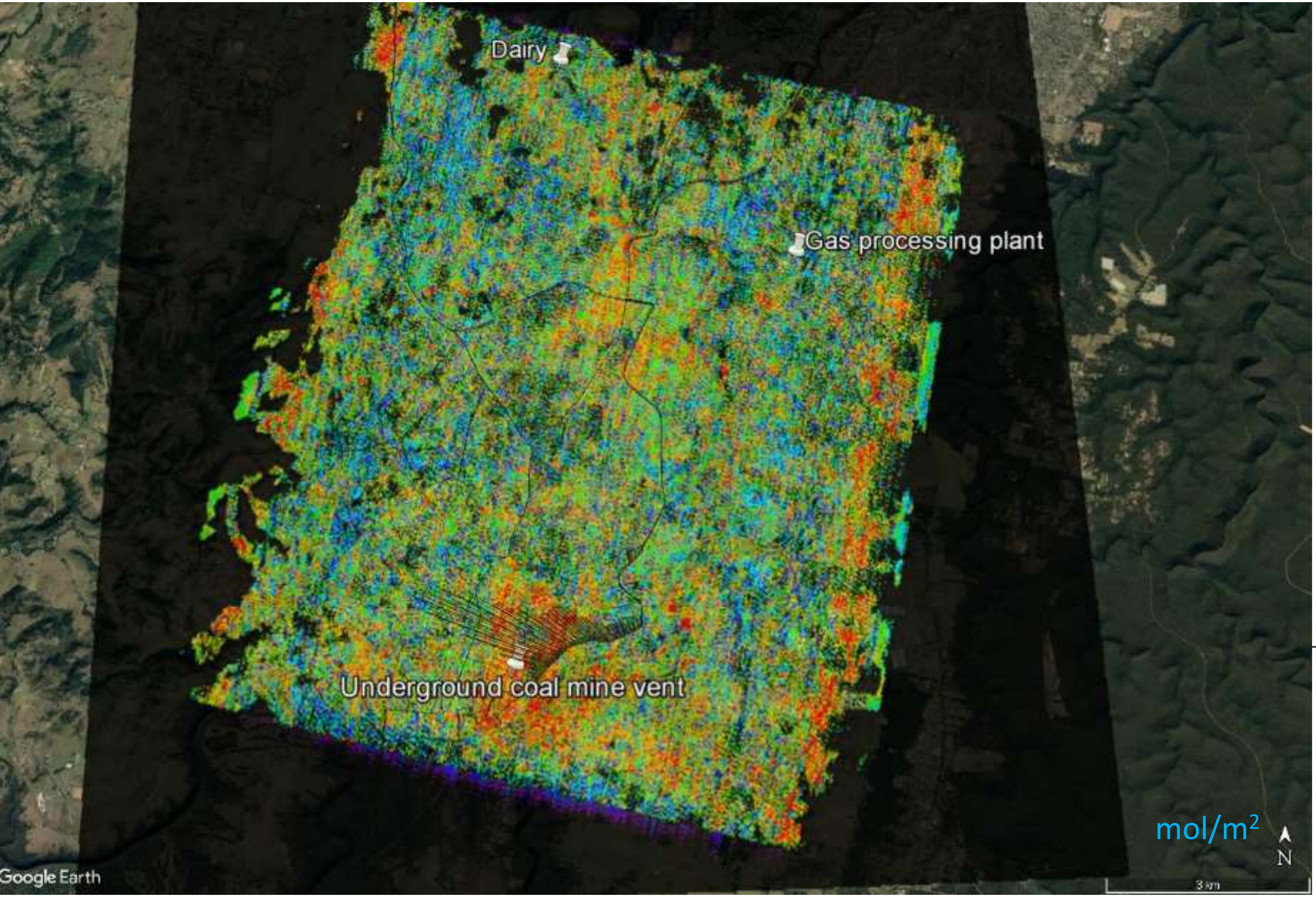
Individual source measurements (e.g., chambers and micrometeorological):
- instantaneous or for longer durations

REMOTE/AERIAL SENSED PLATFORMS





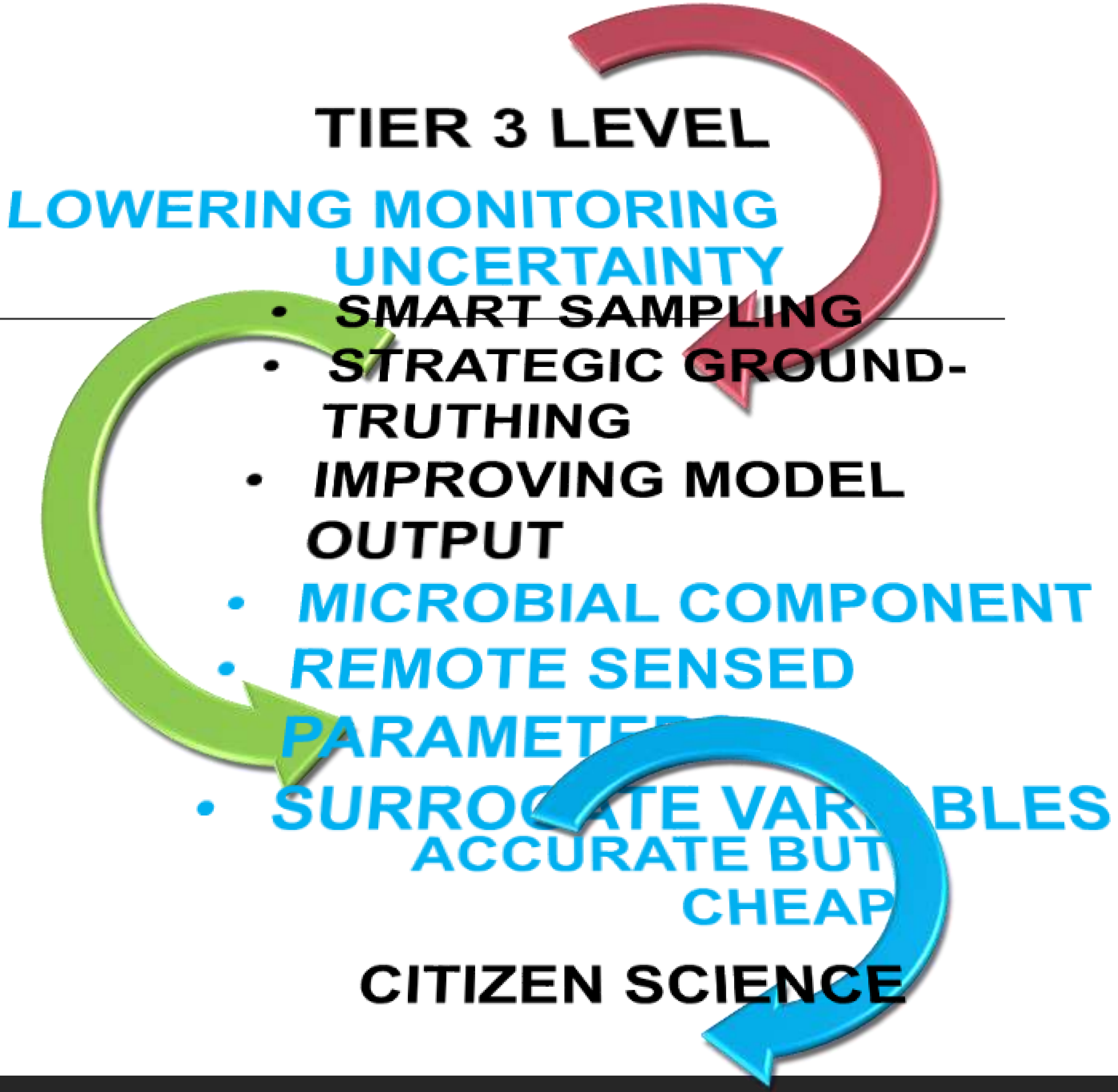
- SCIAMACHY
  SENTINEL 5
- GOSAT
- GeoCARB
- METHANESAT
- IASAI
- GHGsat



CH_4 from GHGSTAT

The measurement of methane from space is a highly demanding task because the sources are usually small, compounded by the large vertical column from space to earth (>500 km),

MONITORING SMARTER AND NOT HARDER



TIER 3 LEVEL

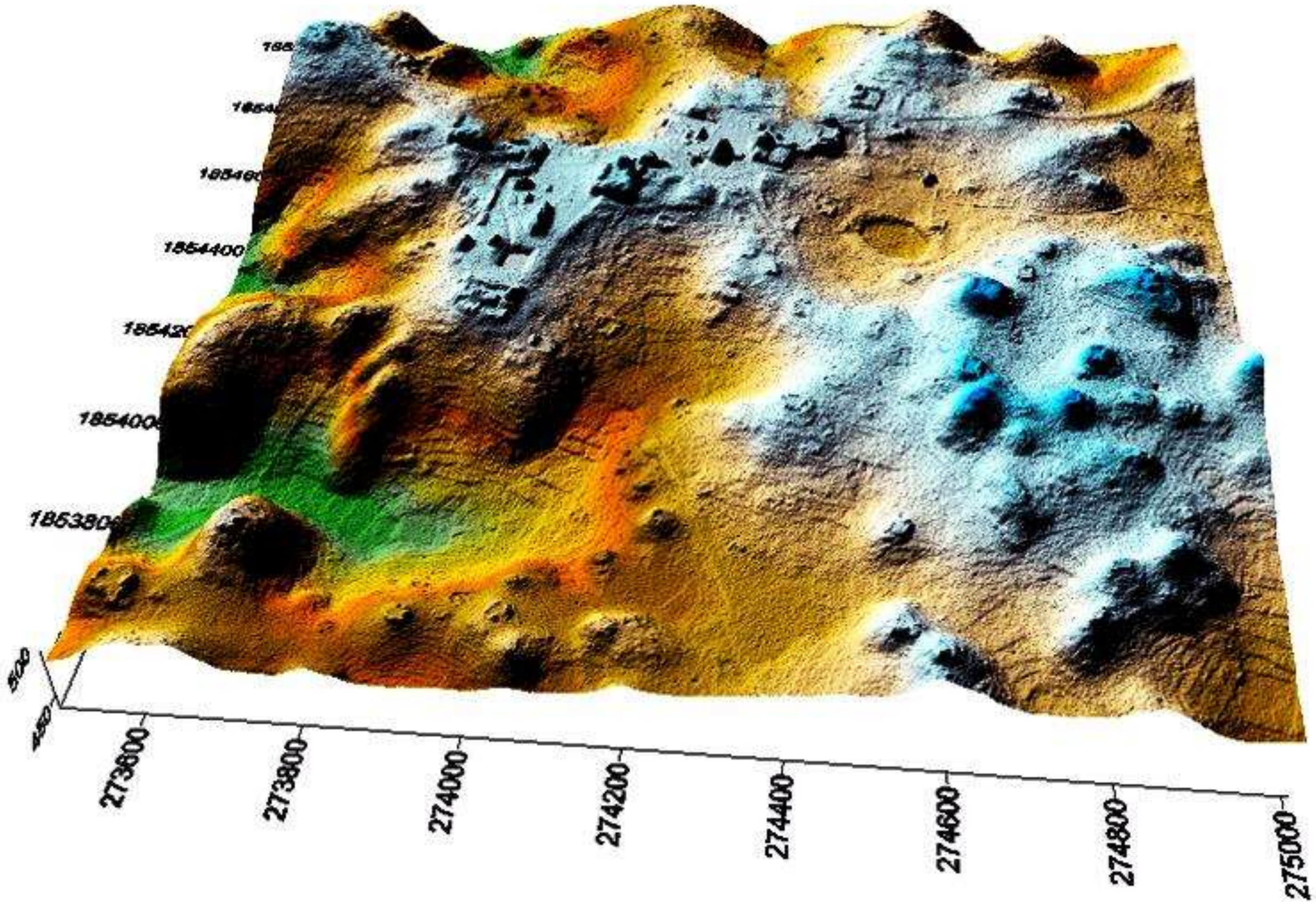
LOWERING MONITORING UNCERTAINTY

- **SMART SAMPLING**
- **STRATEGIC GROUND-TRUTHING**
- ***IMPROVING MODEL OUTPUT***
- ***MICROBIAL COMPONENT***
- ***REMOTE SENSED PARAMETERS***
- **SURROGATE VARIABLES**

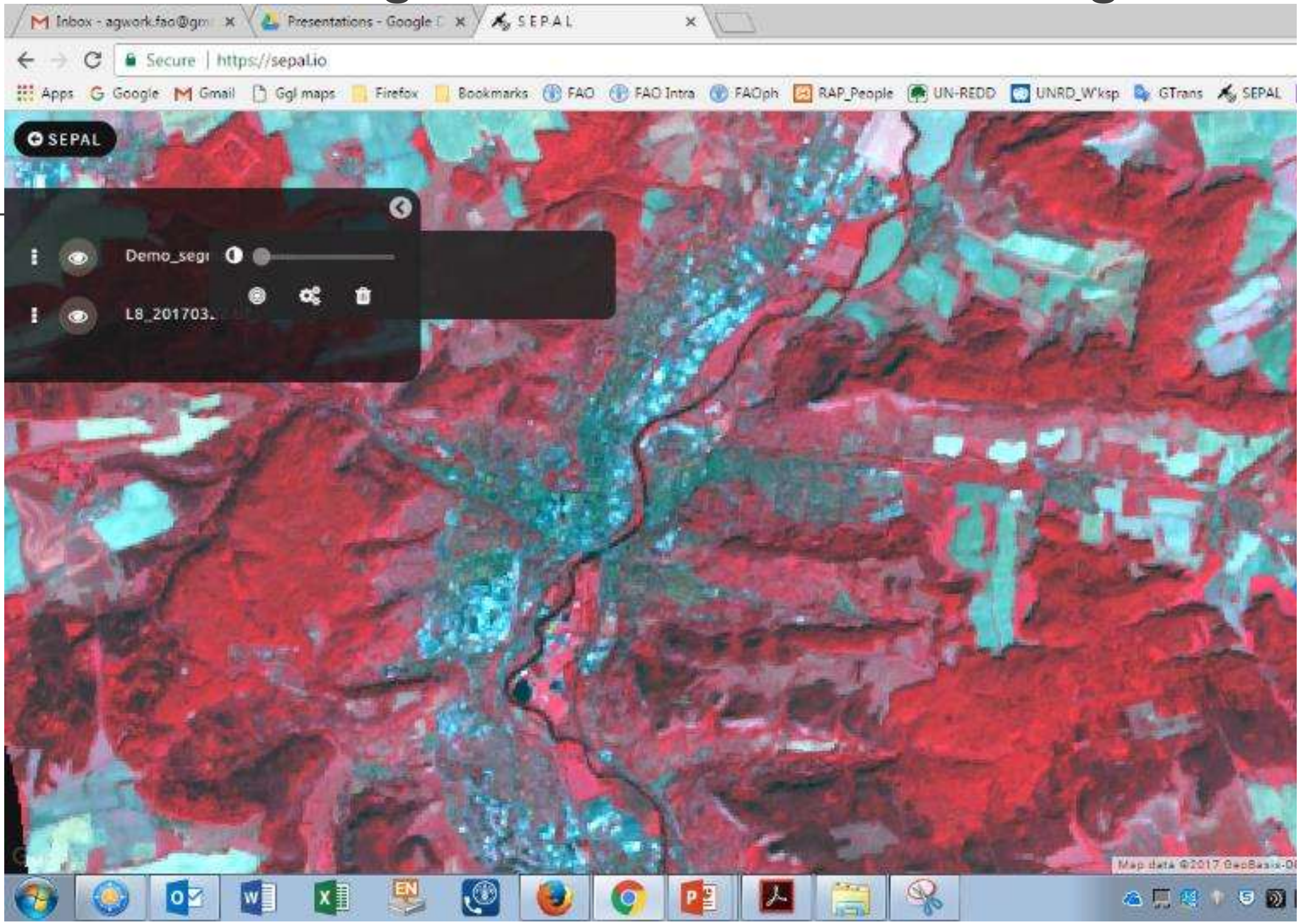
ACCURATE BUT CHEAP

CITIZEN SCIENCE

A hyperspectral image multispectral remote sensing images to inform about sampling

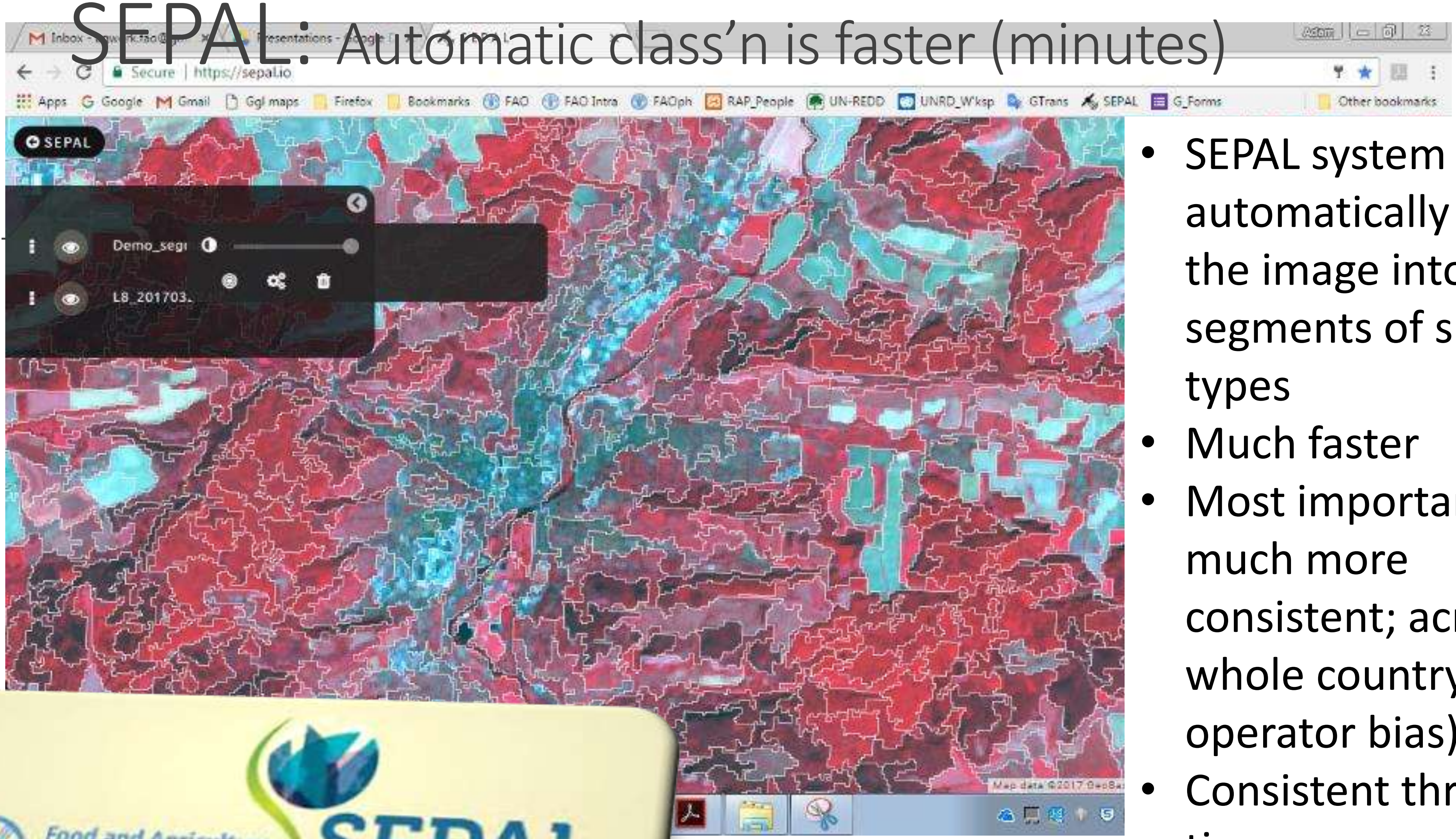


Current Satellite Image classification takes long time



- Typical satellite image in "false colour" where red areas are forest and vegetation
- In Indonesia, assessors manually classify these images visually to areas of similar land cover
- It is difficult, slow work; hard to be consistent over time and between operators

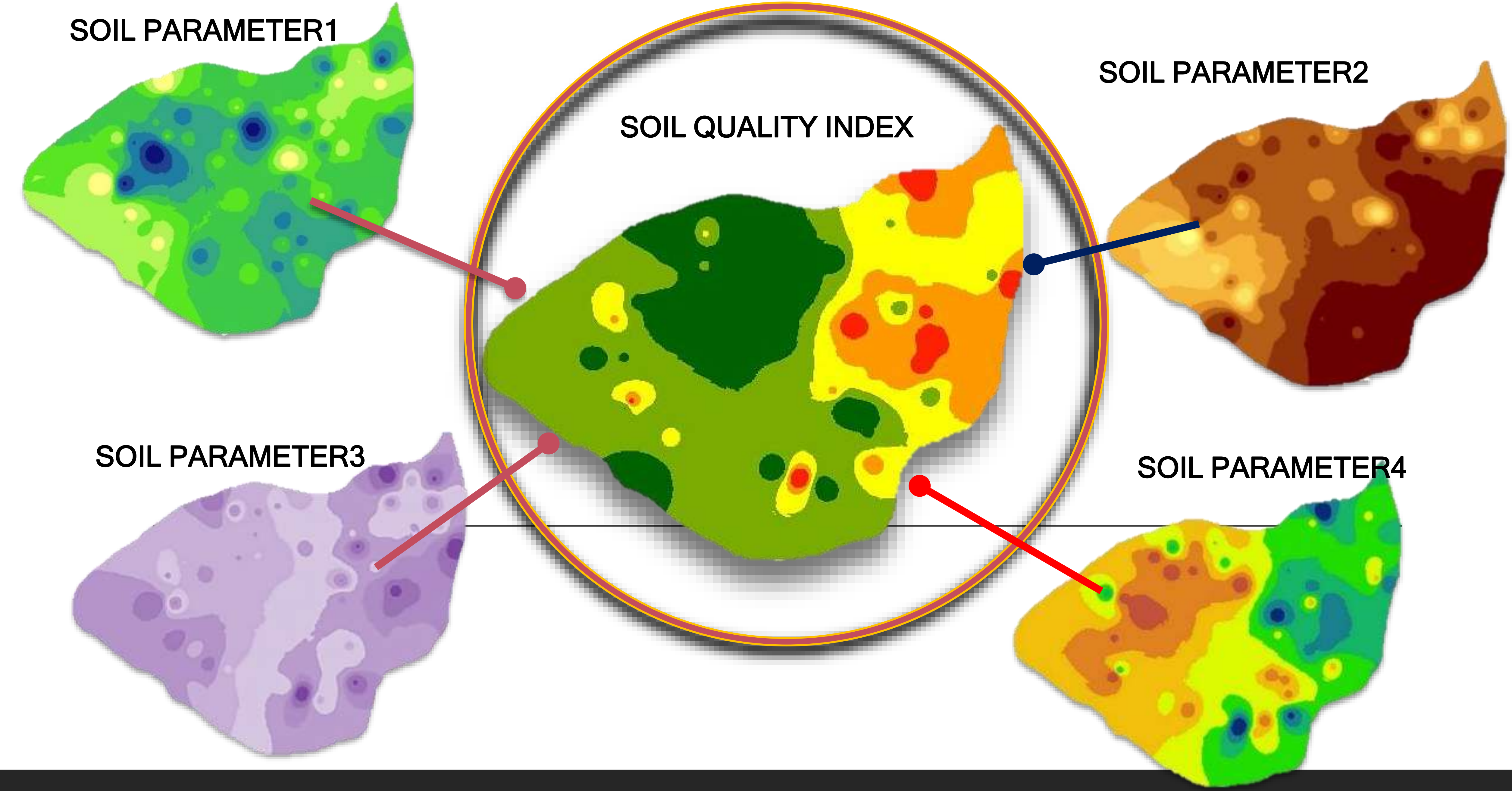
SEPAL: Automatic class'n is faster (minutes)



- SEPAL system can automatically classify the image into segments of similar types
- Much faster
- Most importantly – much more consistent; across the whole country (no operator bias)
- Consistent through time over years

Food and Agriculture Organization of the United Nations

SEPAL
SYSTEM FOR EARTH OBSERVATION DATA ACCESS, PROCESSING & ANALYSIS FOR LAND MONITORING



SOIL PARAMETER1

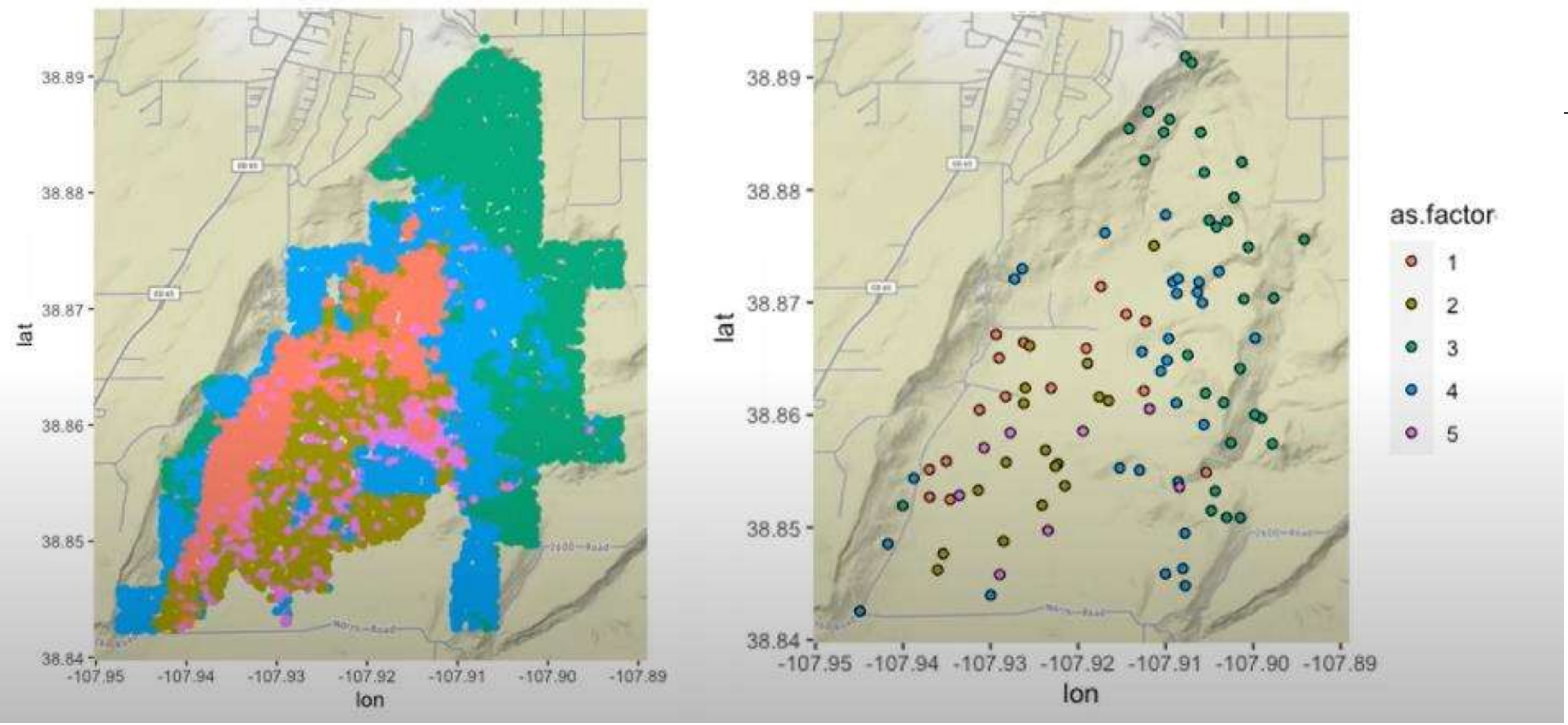
SOIL QUALITY INDEX

SOIL PARAMETER2

SOIL PARAMETER3

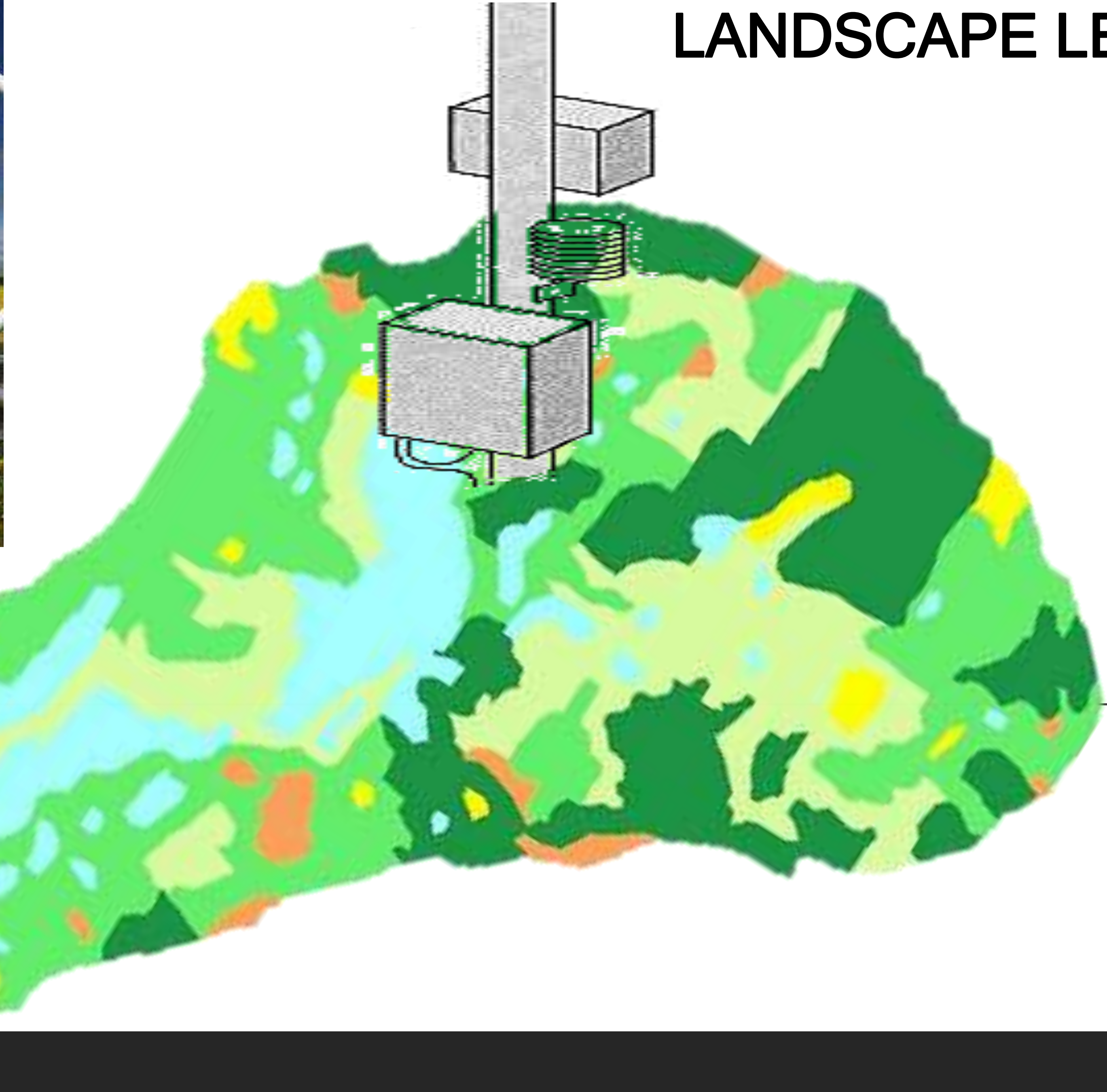
SOIL PARAMETER4

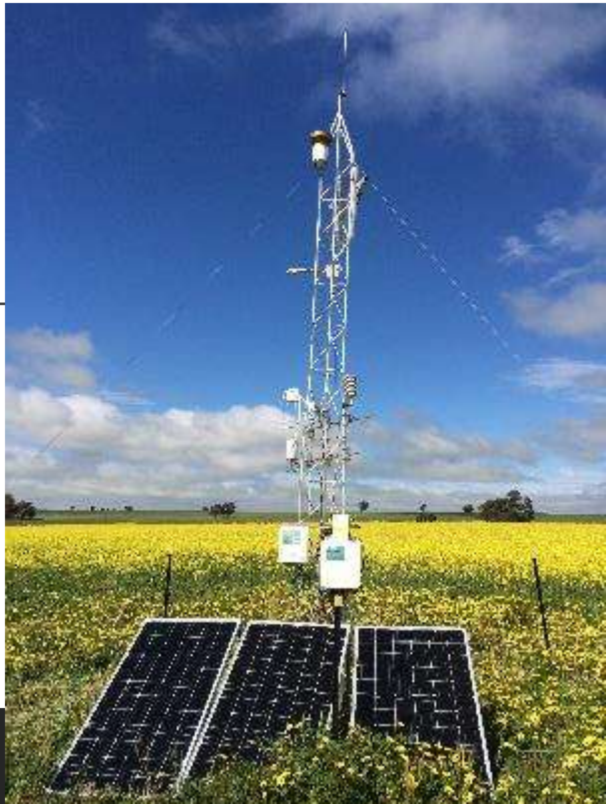
Stratification based upon prior information with data-driven sample selection



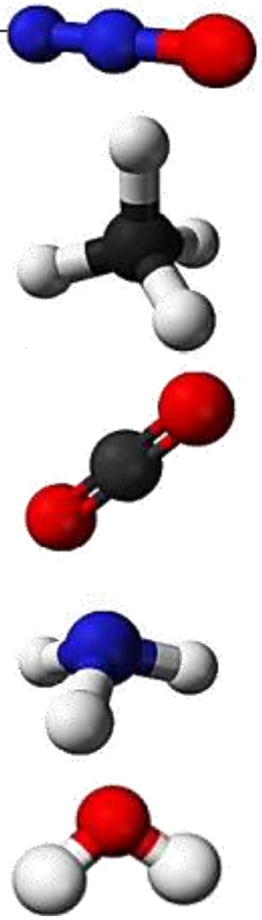
Woodwell Climate Research Centre Jonathan Sandemann

LANDSCAPE LEVEL GHG MRV

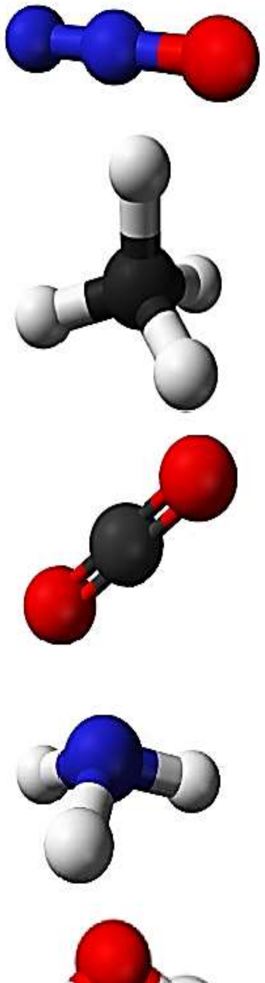





PICARRO



Picarro G2508 Analyzer – Portable in simultaneously measure nitrous oxide (CH4), carbon dioxide (CO2), ammonia (H2O) –



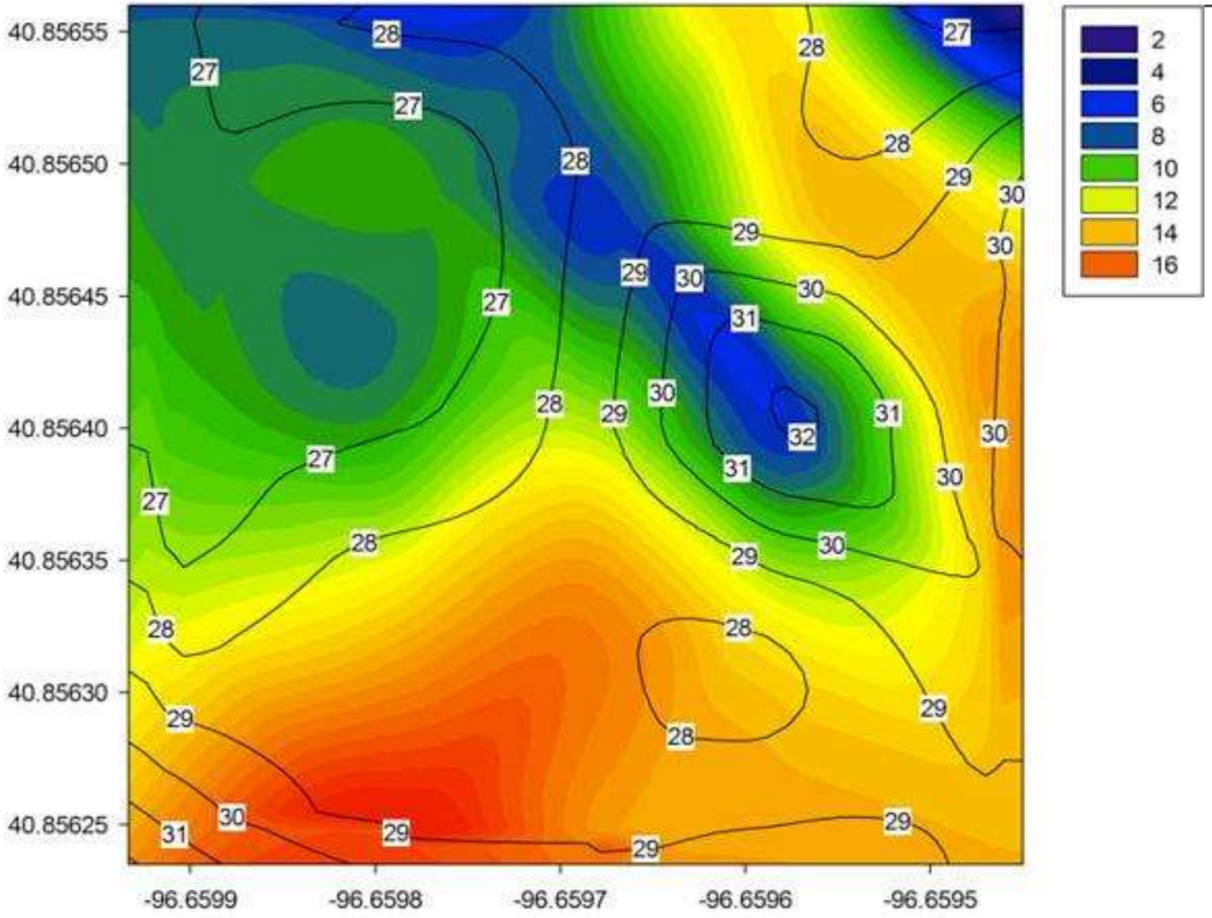
Measurement precisio

N2O: < 5 ppb precision in 5 r

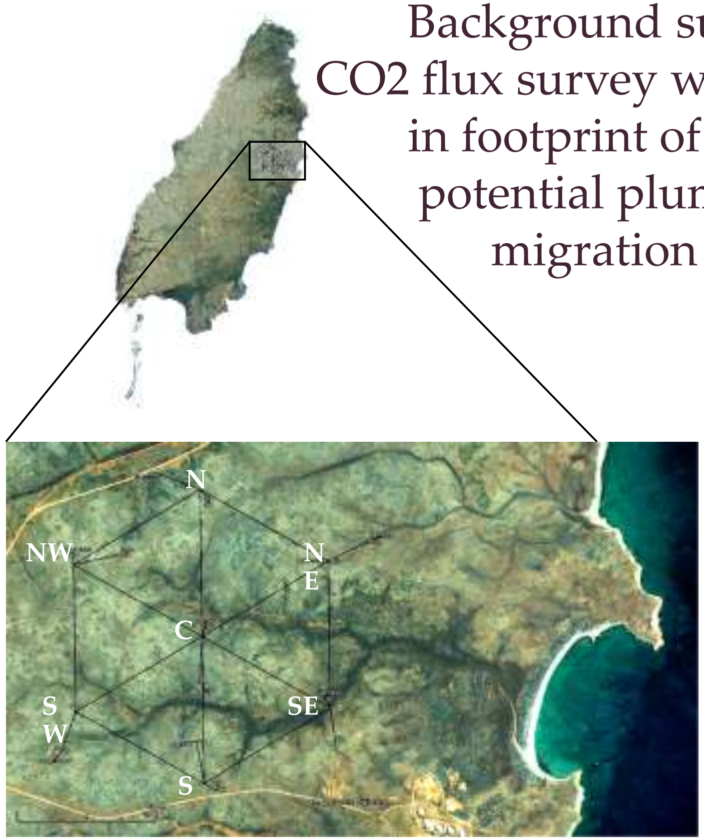
CH4: < 5 ppb precision in 5 r

H2O: < 100 ppm precision ir

Soil CO2 flux /concentration mapping

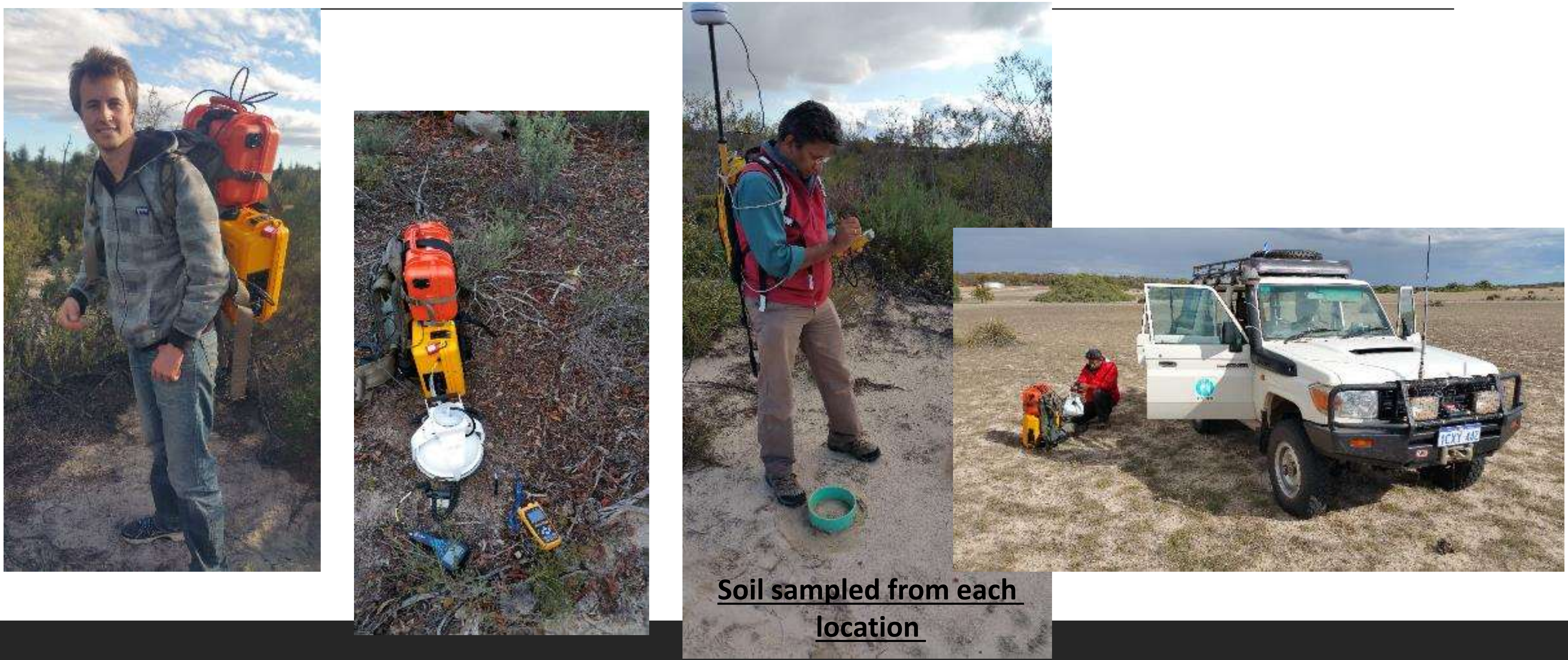


Evaluating spatial variation in soil CO2 flux across the Gorgon CO2 plume area on barrow island, western Australia



Background surface soil CO2 flux survey was carried in footprint of modelled potential plume of CO2 migration following injection

Surface CH4 survey (Winter) Latent



Soil sampled from each location


Warro06
Warro05 Tar
Warro05 Surf
1
2
3
4
5
6
7
8
9
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11
12
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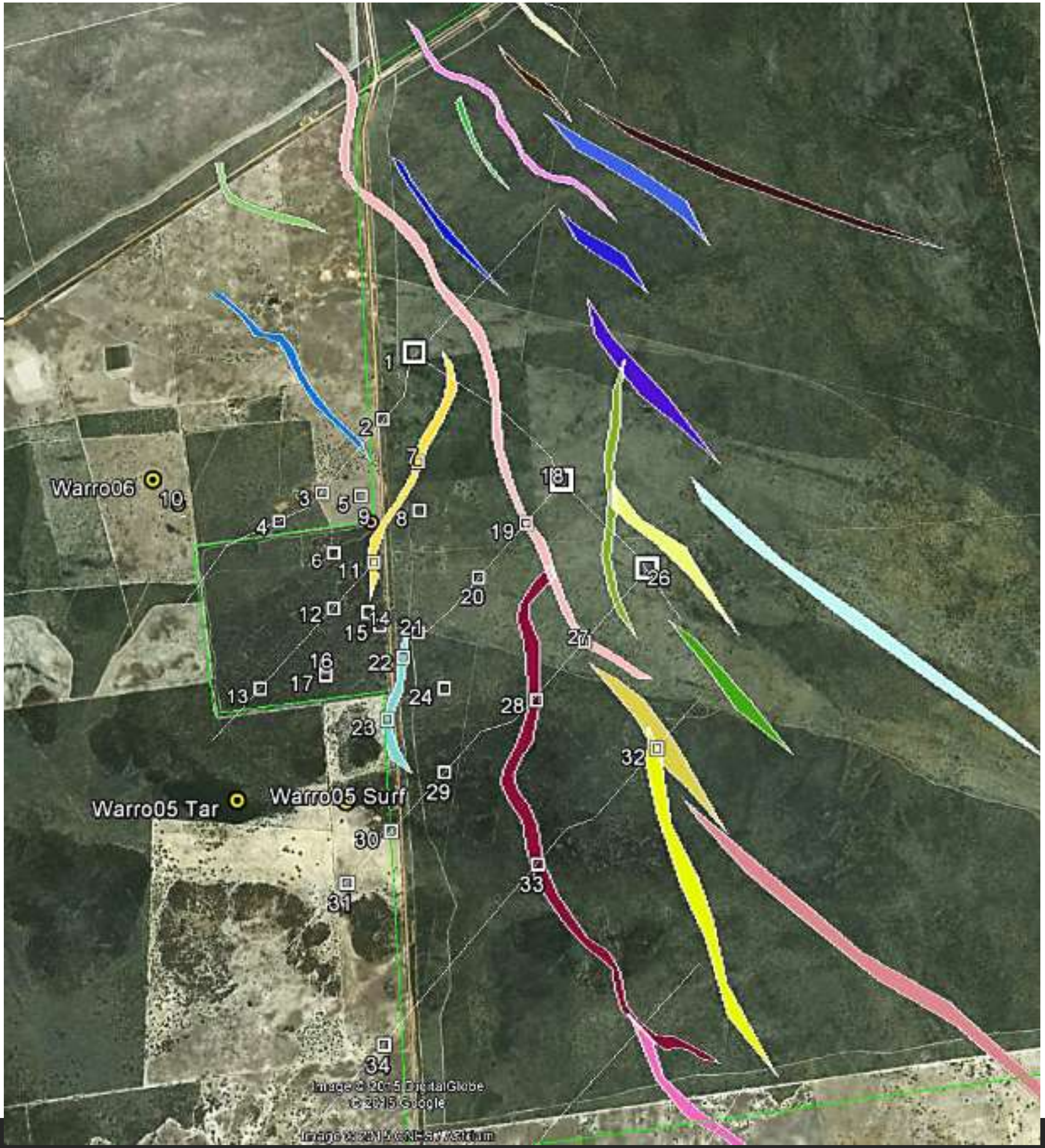
Warro06
Warro05 Tar
Warro05 Surf
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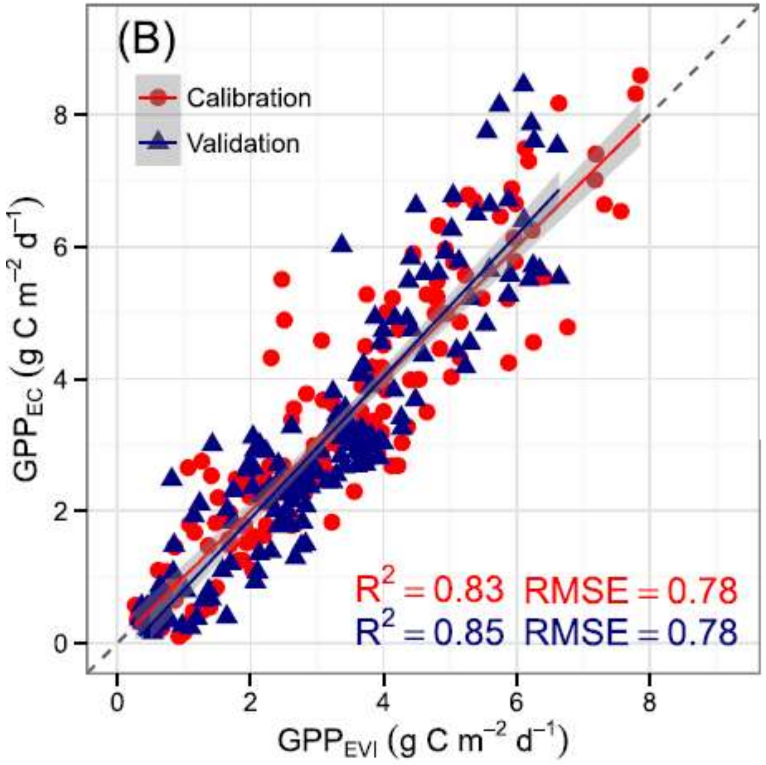
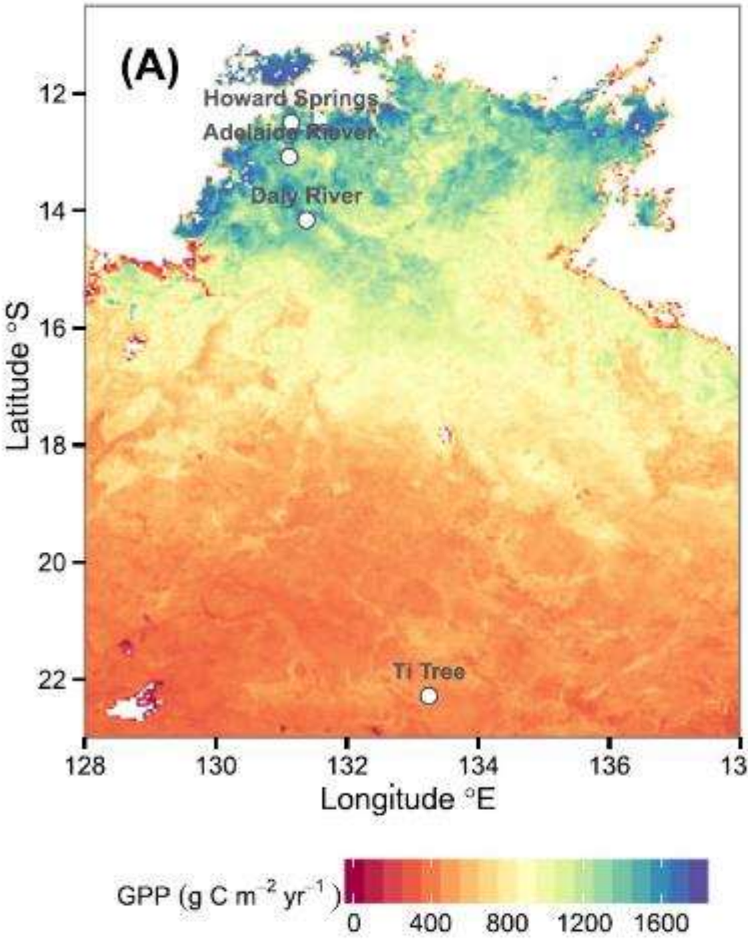
INTEGRATION WITH REMOTE SENSING

- Remote sensing does not measure quantity needed.
- Crucial role in development, calibration and validation.
- Applications from point to landscape to address research question
- Use of spectral indices of vegetation for productivity and ET.
- LiDAR for structure and biomass.
- Microwave for soil moisture, etc.

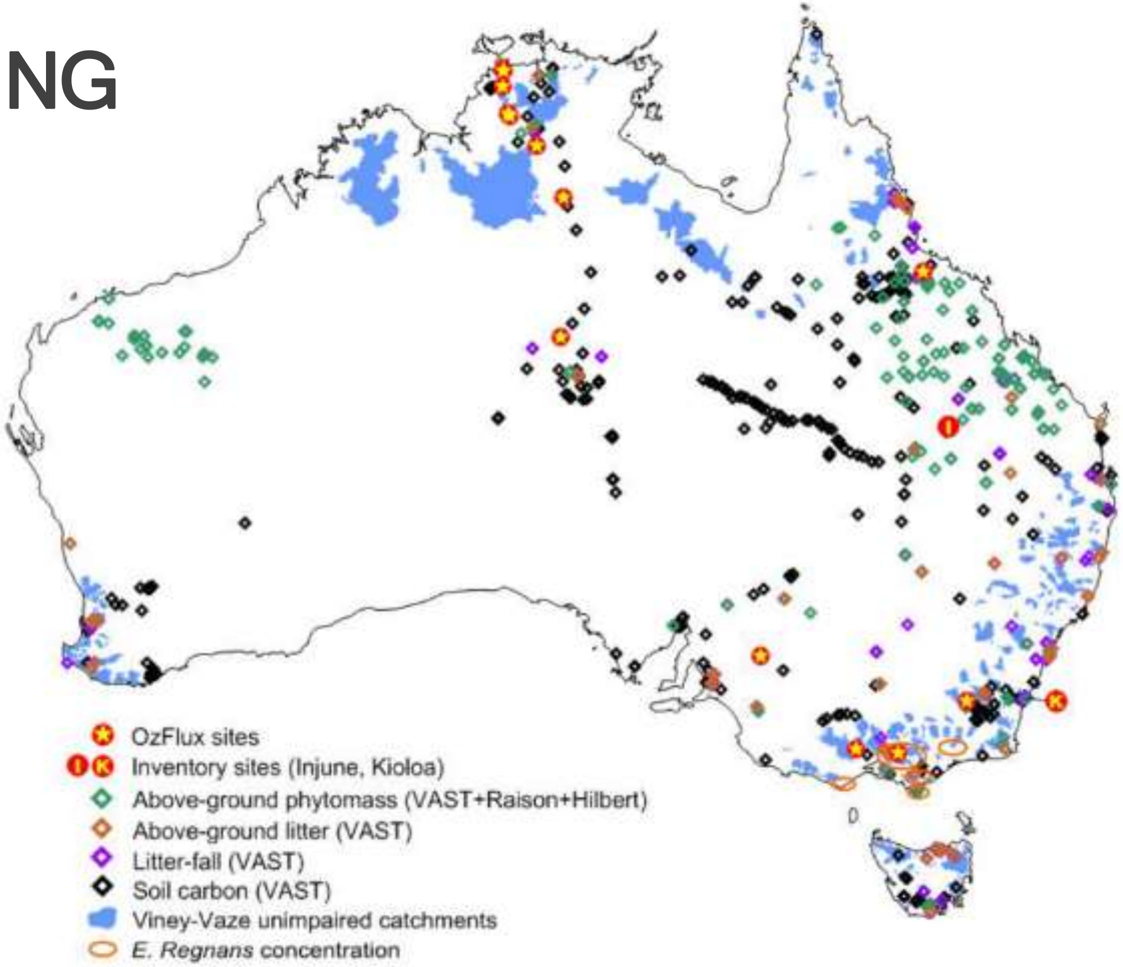




Ma et al. (2014, 2015)

INTEGRATION WITH MODELLING

- Development, calibration and validation.
- DNDC + ORYZA
- Driven by gridded meteorology
- Strategically placing Model-data fusion to construct a consistent parameter set for model uncertainties.



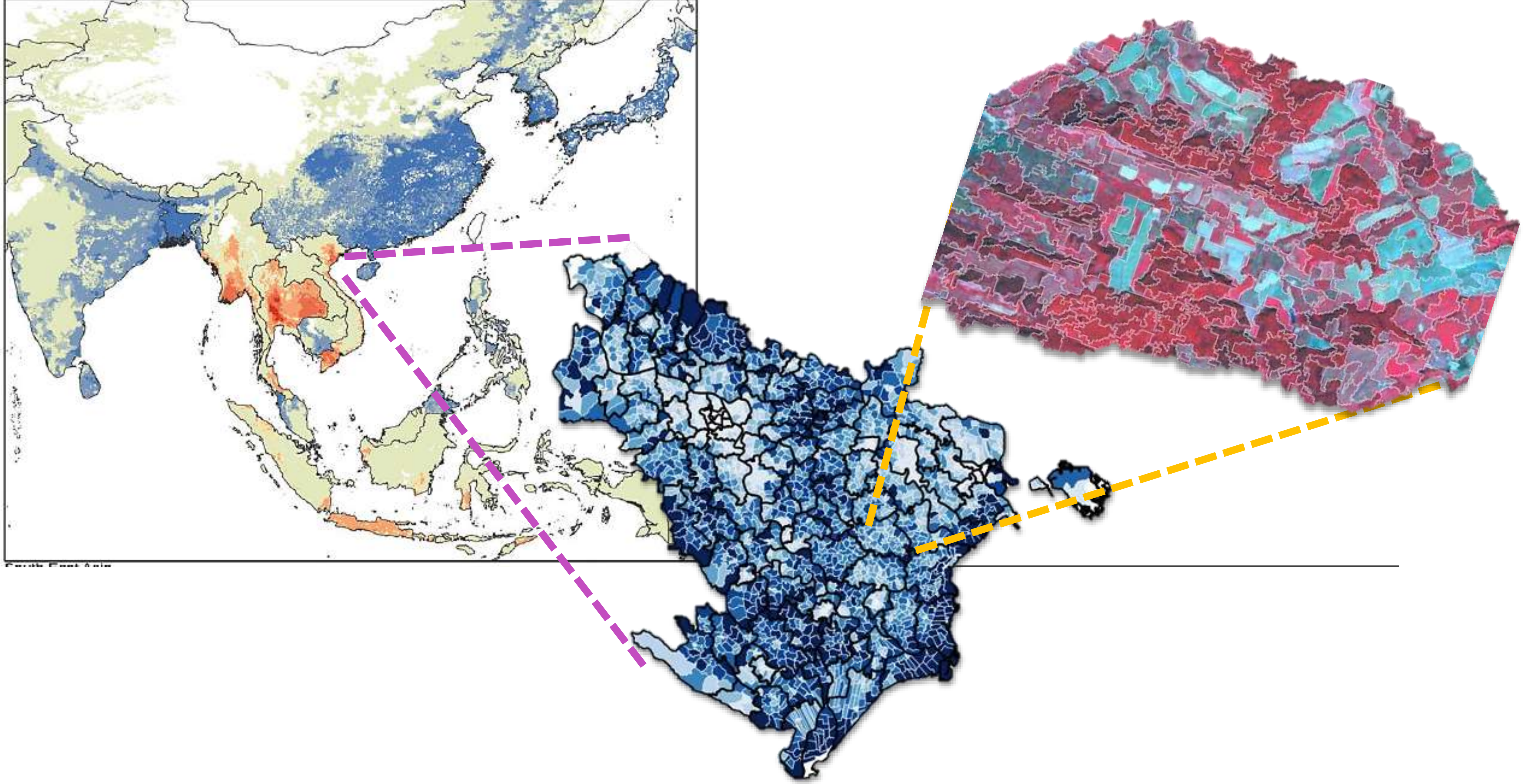
Technology: modeling

DNDC

RothC

Century
100
DayCent

- Markets & protocols are dominated by a handful of traditional models
- Next-gen models better represent modern C concepts
- Extremely high user skill requirements
- Debate over how to represent uncertainty
- Multi-model ensembles are still lacking
- Limited data for model training and validation


South East Asia

A main impetus for constituting the consortium is to bring the fragmented emissions research from institutional/country level to a regionally consistent, scientifically interrogated “package of practices” implemented at a regional scale

ACTION ON EMISSION OF GHGS FOR INTEGRATED SUSTAINABILITY

AEGIS

AEGIS aims to fill knowledge gaps for accurately quantifying GHG emissions when implementing some of the most promising mitigation options.

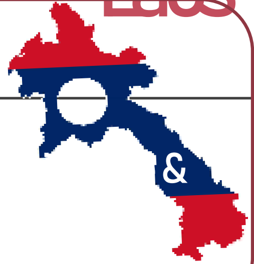
ACTION ON EMISSION OF GHGS FOR INTEGRATED SUSTAINABILITY

AEGIS

Action On Emissions of GHGs for Integrated Sustainability

China

Laos



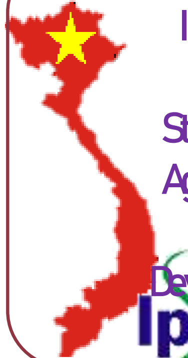
&

Japan

MAFF
Ministry of Agriculture, Forestry and Fisheries
農林水産省

NARO

Vietnam



Institute of Policy and Strategy for Agricultural and Rural Development

Ipsard

Thailand

Rice Department

Cambodia

Indonesia

University

Myanmar

Irrigation

UEA
University of East Anglia

มหาวิทยาลัยนเรศวร

THE UNIVERSITY OF WESTERN AUSTRALIA
SEEK WISDOM

UNIVERSITAS LAMBUNG MANGKURAT

CHINESE ACADEMY OF SCIENCES

IRRI

QUEEN'S UNIVERSITY BELFAST

CEH
Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Bringing together key Strategic Research, Policy and End User Partners to define the barriers to progress in each area, integrate these policy/end user/science challenges into a coherent cross-discipline framework

FAO
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Food and Agriculture Organization of the United Nations

AEGIS
ACTION ON EMISSION OF GHGS FOR INTEGRATED SUSTAINABILITY