Expectations from satellite observations

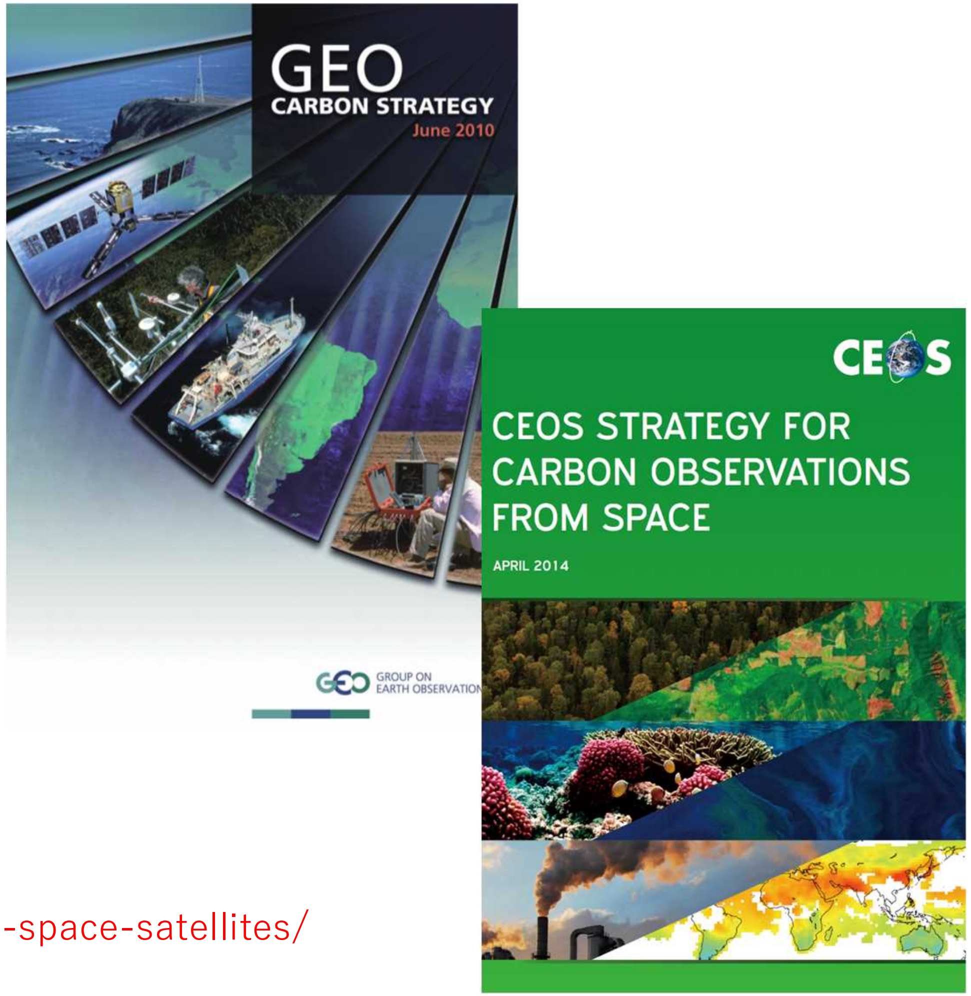
Osamu Ochiai, JAXA
AOGEO Symposium
TG-2 and 3 joint session
November 3, 2019, Canberra, Australia

Committee on Earth Observation Satellites

- CEOS was established in September, 1984 (G7 Summit)
- 34 Space Agencies & 28 Associates with 170 Satellites
- CEOS is the mechanism that brings these organisations together to collaborate on missions, data systems, and global initiatives that benefit society and align with their own Agency missions and priorities.
- CEOS is a PO of GEO
- CEOS Objectives:
  - To optimize the benefits of space-based Earth observation through cooperation of CEOS Agencies in mission planning and in the development of **compatible data products, formats, services, applications and policies**
  - To aid both CEOS Agencies and **the international user community** by, among other things, serving as the focal point for international coordination of space-based Earth observation activities, including **the Group on Earth Observations and entities related to global change**
  - To exchange policy and technical information to encourage complementarity and compatibility among space-based Earth observation systems currently in service or development, and the data received from them, as well as address issues of common interest across the spectrum of Earth observation satellite missions

CEOS Carbon activity - history and Background

- GEO Carbon Report developed in June 2010 by team led by Ciais et al. (GCP).
- *CEOS Strategy for Carbon Observations from Space* – written in response to above, completed in March 2014 – *Wickland et al.*
- 42 Actions identified in the report for specific response– first discussed at CEOS SIT Technical Workshop in September 2013
- April 2014:Proposed establishment of a study team to take forward the Actions and also identify formal CEOS mechanism to manage Actions.
- CEOS Plenary 2016: Agreed approach with dedicated pilots activities



GEO
CARBON STRATEGY
June 2010

GEO GROUP ON EARTH OBSERVATIONS

CEOS

CEOS STRATEGY FOR CARBON OBSERVATIONS FROM SPACE

APRIL 2014

http://ceos.org/home-2/the-ceos-carbon-strategy-space-satellites/

2019 Refinement IPCC Guideline (GHG Inventory)

Task Force on
National Greenhouse Gas Inventories

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

[Old] 2006 IPCC Guidelines for GHG Inventories

Volume 1 Chapter 6: Quality Assurance /Quality Control and Verification

[6.10.2 Comparisons with atmospheric measurements]

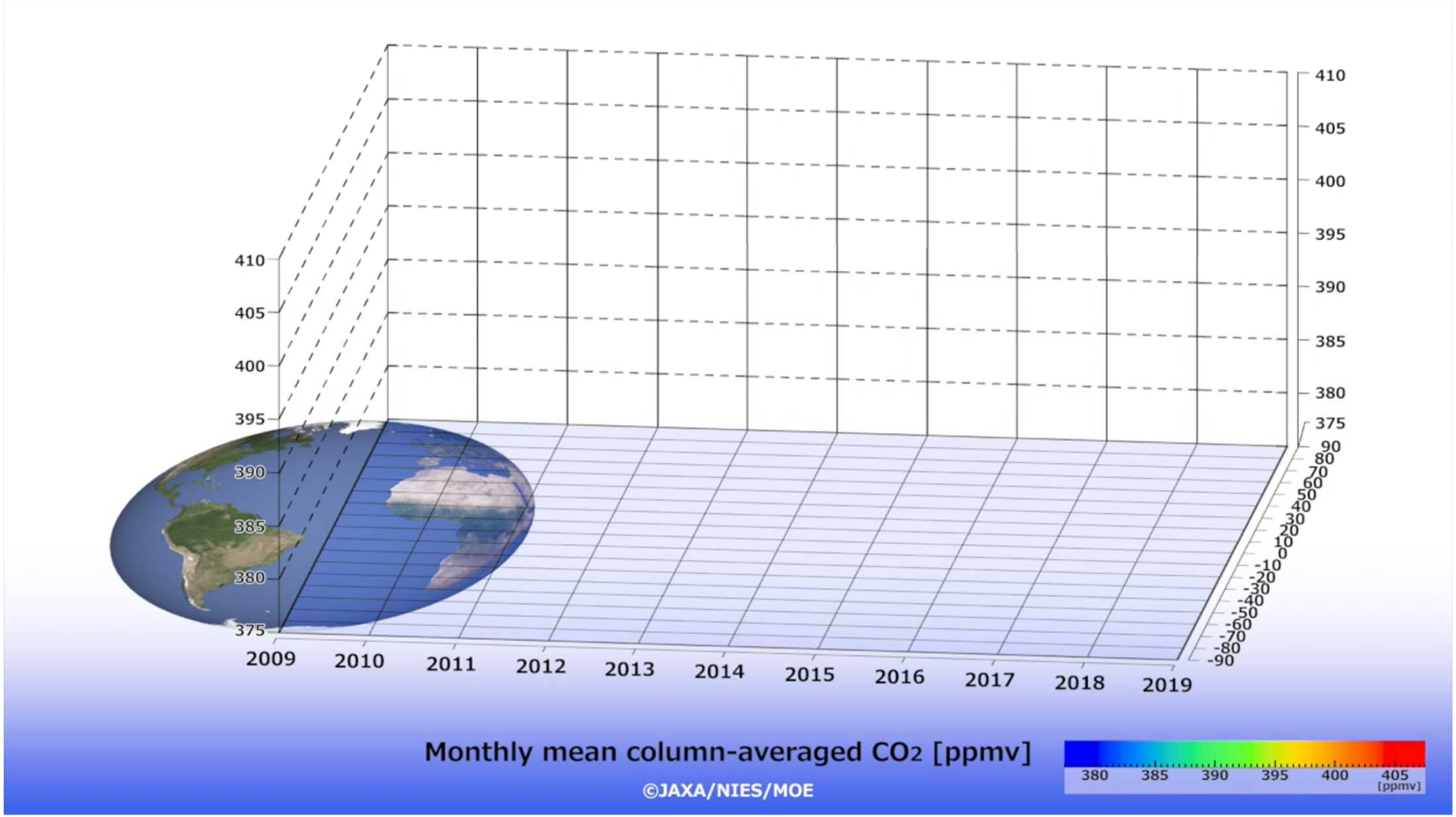
- Considering the limited monitoring network currently available for many of the greenhouse gases and the resulting uncertainties in the model results, inverse modeling is not likely to be frequently applied as a verification tool of national inventories in the near future. Even the availability of satellite-borne sensors for greenhouse gas concentration measurements will not fully resolve this problem, due to limitations in spatial, vertical and temporal resolution (*).

[New] Refinement to 2006 IPCC Guidelines for GHG Inventories

Volume 1 Chapter 6: Quality Assurance/Quality Control and Verification

- Delete: Descriptions about limitation on availability of satellite observations (* the left)
- Add: Many descriptions on usability and roles of satellite data as a comparison tool of inventories. Particularly, a new section of “Satellite Observations” are included.
  - Improvement of estimation accuracy of model by satellite data utilization at the area that in-situ data is not ready fully.
  - Prospects that satellite data estimation will quickly improve because of increase in the number of observations by new GHG observation satellites (TROPOMI, GOSAT-2, GeoCarb, TanSat etc.)

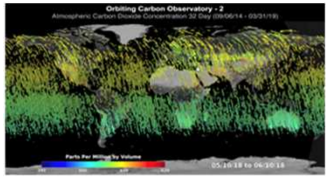
A Decade-Long Global GHG Observation by GOSAT

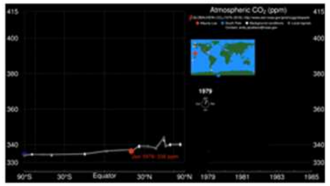


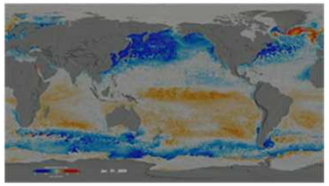
The Architecture Exploits the Evolving Fleet of CO_2 and CH_4 Satellites

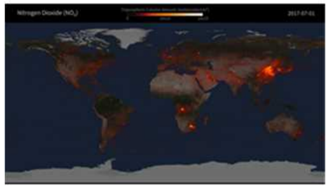
- **Space agencies have supported several pioneering space-based GHG sensors**
  - SCIAMACHY on ESA's ENVISAT
  - Japan's GOSAT TANSO-FTS, NASA's OCO-2, China's TanSat AGCS, Feng Yun-3D GAS and Gaofen-5 GMI, Copernicus Sentinel 5 Precursor TROPOMI, Japan's GOSAT-2 TANSO-FTS-2 and NASA's ISS OCO-3
- **Others are under development**
  - CNES MicroCarb, CNES/DLR MERLIN, NASA's GeoCarb
- **Others are in the Planning stages**
  - Japan's GOSAT Follow-on, Copernicus CO2M

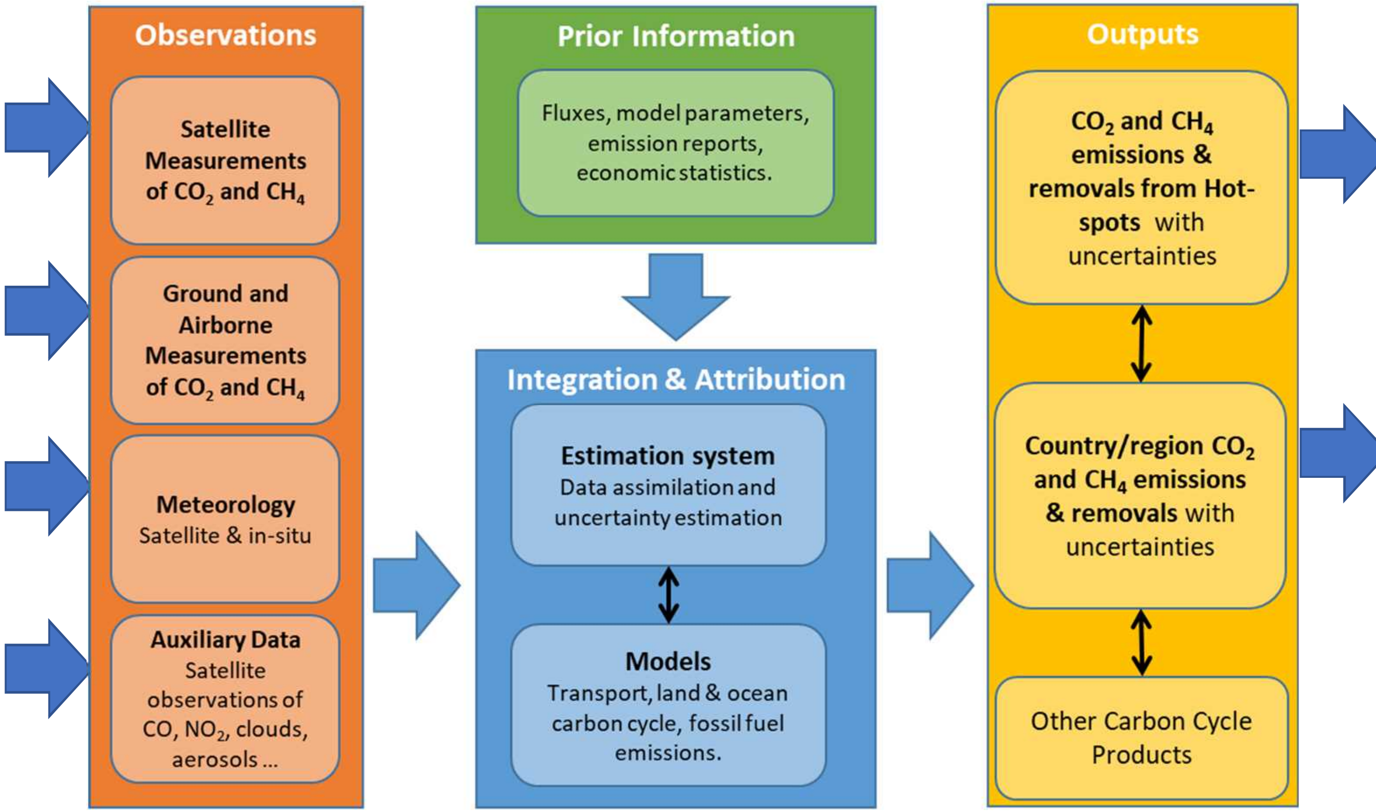
A System Approach is Adopted to Deliver Atmospheric CO_2 and CH_4 Inventories











Observations

Satellite Measurements of CO_2 and CH_4

Ground and Airborne Measurements of CO_2 and CH_4

Meteorology
Satellite & in-situ

Auxiliary Data
Satellite observations of CO, NO_2, clouds, aerosols …

Prior Information

Fluxes, model parameters, emission reports, economic statistics.

Integration & Attribution

Estimation system
Data assimilation and uncertainty estimation

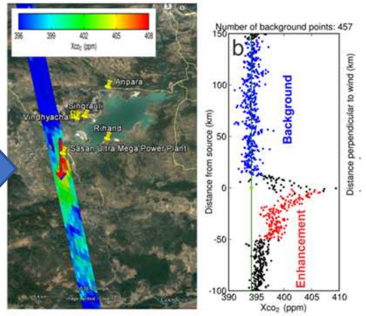
Models
Transport, land & ocean carbon cycle, fossil fuel emissions.

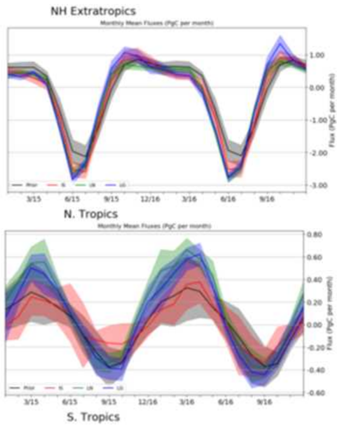
Outputs

CO_2 and CH_4 emissions & removals from Hot-spots with uncertainties

Country/region CO_2 and CH_4 emissions & removals with uncertainties

Other Carbon Cycle Products

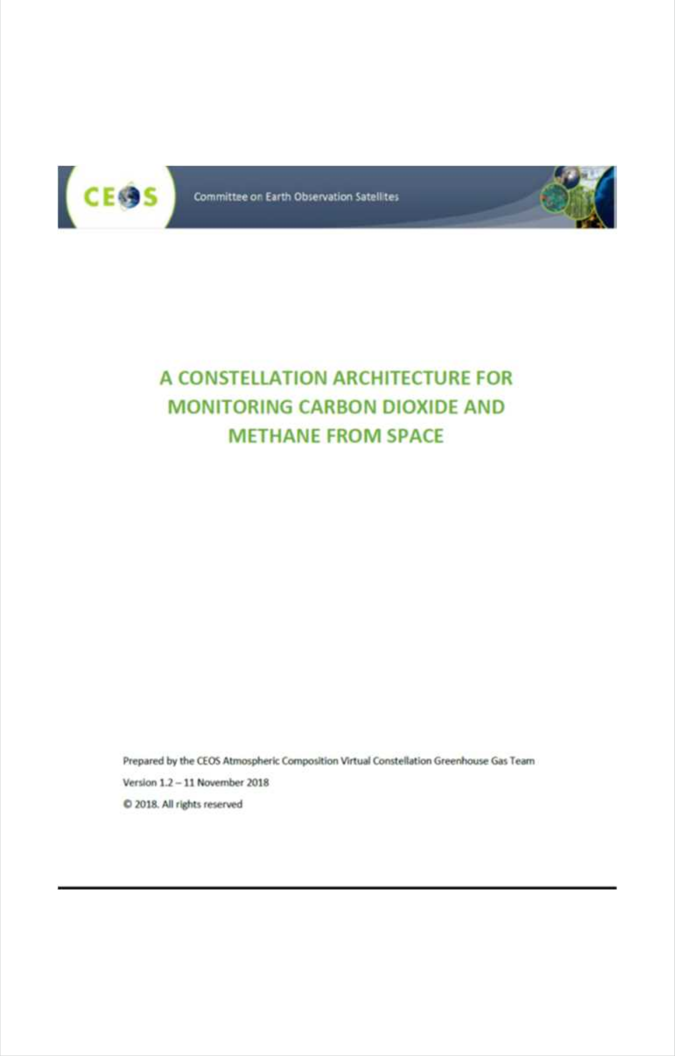




Developing Atmospheric GHG Inventories

The CEOS GHG White Paper recommends the following approach:

1. **Refine requirements for atmospheric flux inventories**
    - Foster collaboration between the space-based and ground-based GHG measurement and modeling communities and the bottom-up inventory and policy communities
2. **Produce a prototype atmospheric CO_2 and CH_4 flux inventory that is available in time to inform the bottom-up inventories for the 2023 global Stocktake**
    - Coordinate ongoing missions and atmospheric inversion efforts to produce a best-effort inventory
3. **Use lessons learned from the prototype flux inventory to refine requirements**
    - A future, purpose-built, operational, atmospheric inventory system
    - Improved atmospheric GHG inventories to support the 2028 global Stocktake and beyond



CEOS Committee on Earth Observation Satellites

A CONSTELLATION ARCHITECTURE FOR MONITORING CARBON DIOXIDE AND METHANE FROM SPACE

Prepared by the CEOS Atmospheric Composition Virtual Constellation Greenhouse Gas Team

Version 1.2 – 11 November 2018

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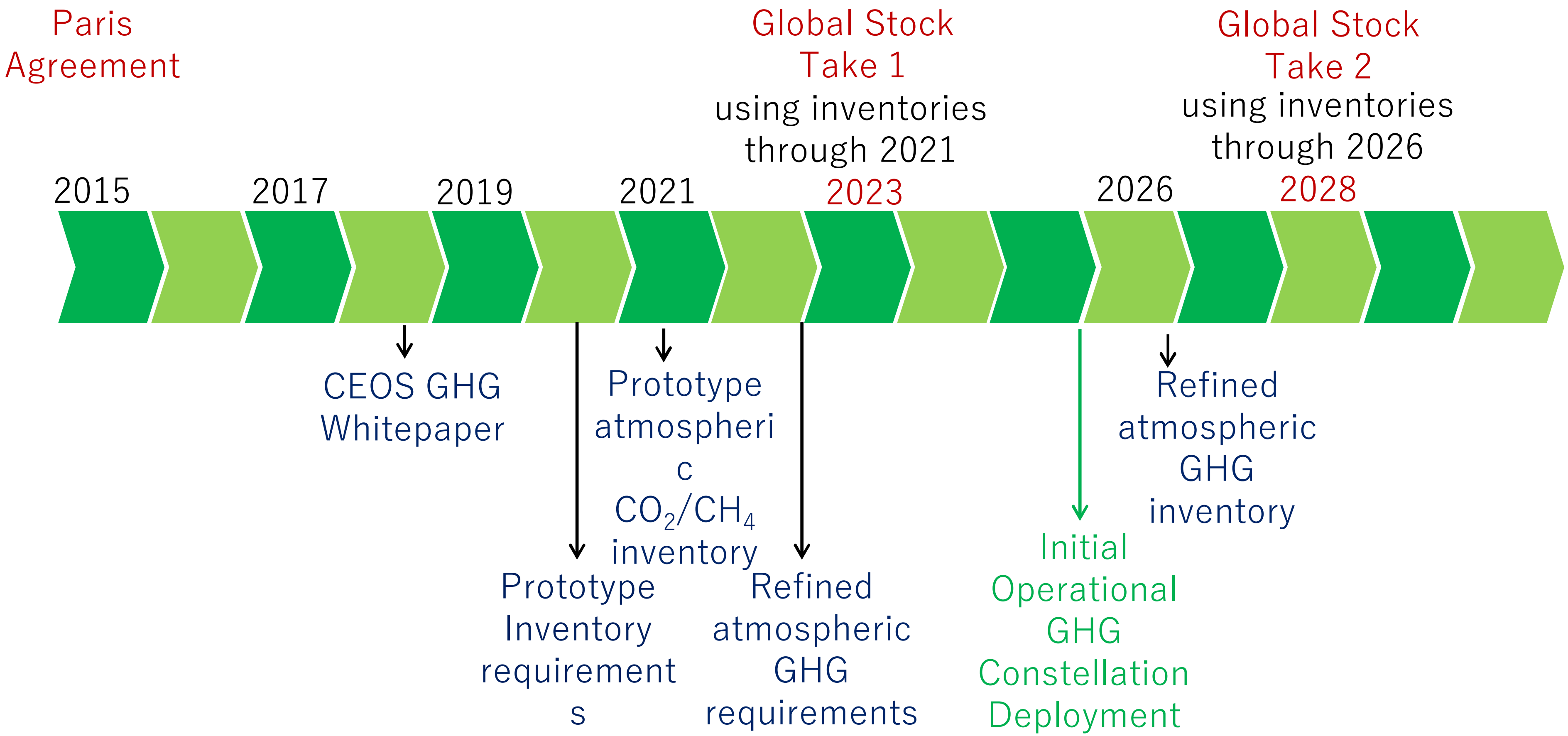
CEOS GHG Roadmap Timeline



Paris Agreement

Global Stock Take 1
using inventories through 2021

Global Stock Take 2
using inventories through 2026

2015
2017
2019
2021
2023
2026
2028

CEOS GHG Whitepaper

Prototype Inventory requirements

Prototype atmospheric CO_2/CH_4 inventory

Refined atmospheric GHG requirements

Initial Operational GHG Constellation Deployment

Refined atmospheric GHG inventory

2019 Refinement IPCC Guideline (AFOLU)

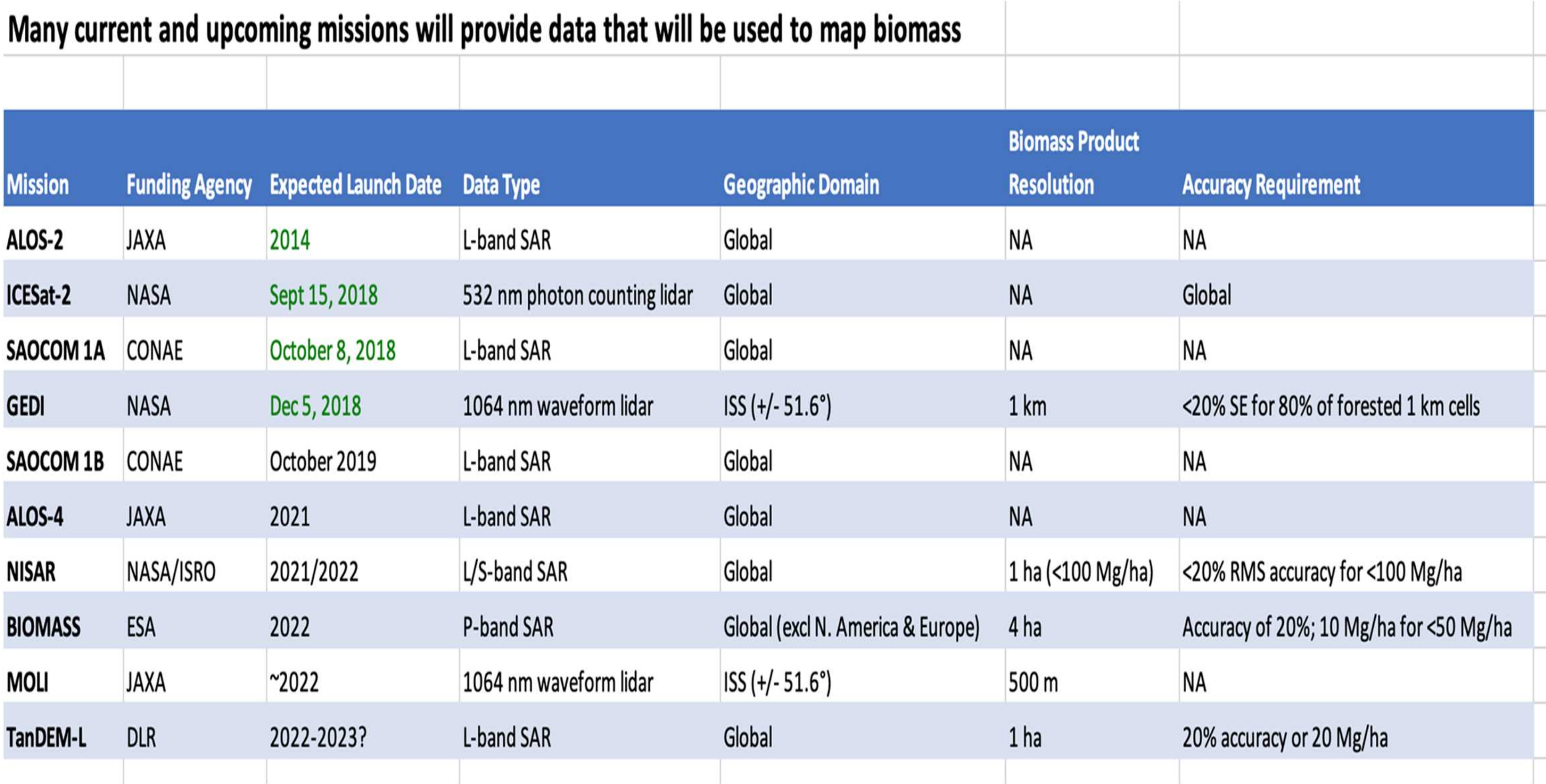
**Task Force on
National Greenhouse Gas Inventories**

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories on AFOLU (Agriculture Forestry and Other Land Use)
Volume 4 (AFOLU), Chapter 2, Page 2.20, BOX 2.0D (NEW) REMOTE SENSING TECHNOLOGIES

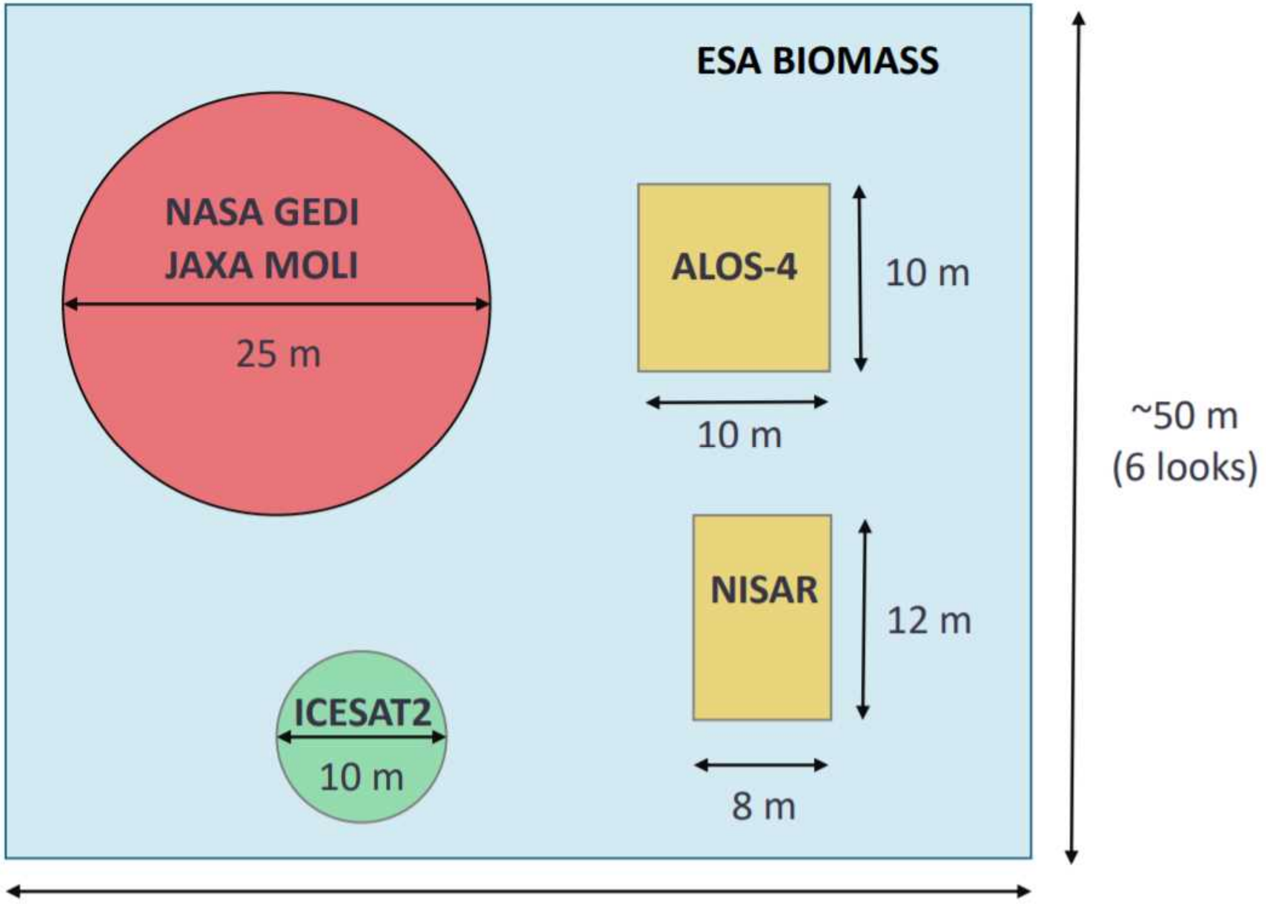
- Optical, Synthetic Aperture Radar (SAR) and Light Detection and Ranging (Lidar) sensors are available currently as remote sensing data sources for producing biomass density maps.
- SAR and LiDAR are active sensors available as air borne and space borne instruments whose derived metrics are used to predict height, volume or biomass of woody plants and trees.
- Referring missions: Landsat, Sentinel-1/2, ALOS-1/2, BIOMASS, NISAR, GEDI, ICESAT-2, Rapideye, and SPOT

Biomass missions



Many current and upcoming missions will provide data that will be used to map biomass

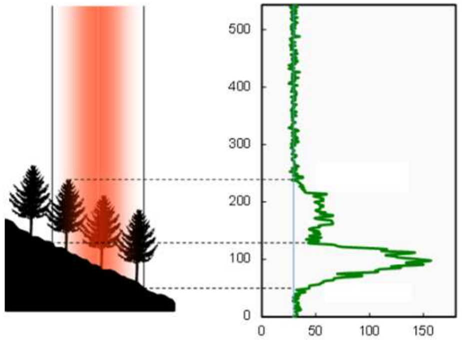
Mission	Funding Agency	Expected Launch Date	Data Type	Geographic Domain	Biomass Product Resolution	Accuracy Requirement
ALOS-2	JAXA	2014	L-band SAR	Global	NA	NA
ICESat-2	NASA	Sept 15, 2018	532 nm photon counting lidar	Global	NA	Global
SAOCOM 1A	CONAE	October 8, 2018	L-band SAR	Global	NA	NA
GEDI	NASA	Dec 5, 2018	1064 nm waveform lidar	ISS (+/- 51.6°)	1 km	<20% SE for 80% of forested 1 km cells
SAOCOM 1B	CONAE	October 2019	L-band SAR	Global	NA	NA
ALOS-4	JAXA	2021	L-band SAR	Global	NA	NA
NISAR	NASA/ISRO	2021/2022	L/S-band SAR	Global	1 ha (<100 Mg/ha)	<20% RMS accuracy for <100 Mg/ha
BIOMASS	ESA	2022	P-band SAR	Global (excl N. America & Europe)	4 ha	Accuracy of 20%; 10 Mg/ha for <50 Mg/ha
MOLI	JAXA	~2022	1064 nm waveform lidar	ISS (+/- 51.6°)	500 m	NA
TanDEM-L	DLR	2022-2023?	L-band SAR	Global	1 ha	20% accuracy or 20 Mg/ha


ESA BIOMASS
NASA GEDI
JAXA MOLI
25 m
ALOS-4
10 m
10 m
NISAR
12 m
8 m
ICESAT2
10 m
~50 m
(6 looks)

Case study: Forest above-ground biomass map development

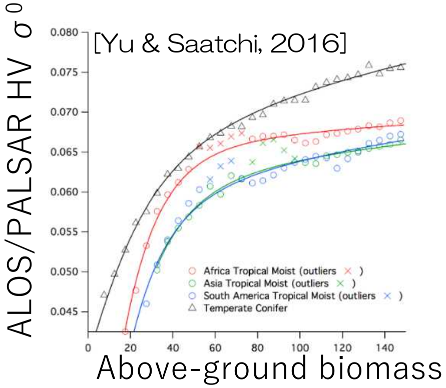
Biomass observation using active sensors

LiDAR



- ☐ LiDAR waveform can be used for accurate estimation of above-ground biomass.
- ☐ Spatial distribution is limited to discrete footprint points.

SAR



[Yu & Saatchi, 2016]

- ☐ HV polarization image can be used for estimation of above-ground biomass.
- ☐ Signal saturation occurs at high biomass forests.
- ☐ Polarization image ratio, image texture, coheren **time-series data** are used for saturation point enhancement.

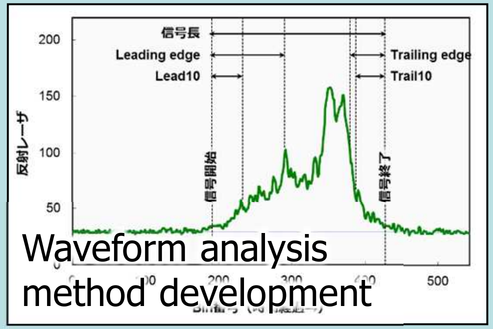
Case study: Forest above-ground biomass map development

Analysis method

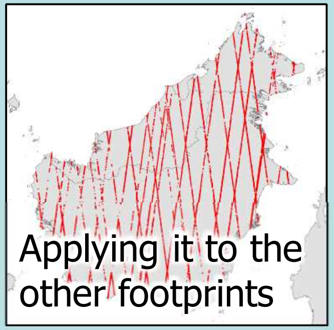
ICESat/GLAS

[Hayashi et al., 2015]

AGB measurement



Waveform analysis method development

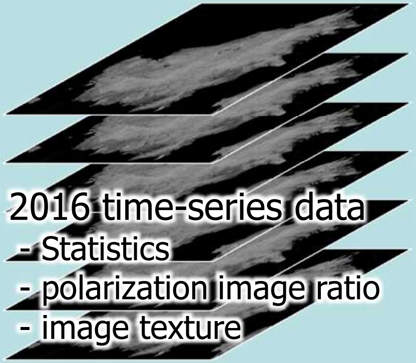


Applying it to the other footprints

Training/Validation data

- adjusted AGB according to the time-lag
- divided 9:1 for training and validation

ALOS-2/PALSAR-2



2016 time-series data

- Statistics
- polarization image ratio
- image texture

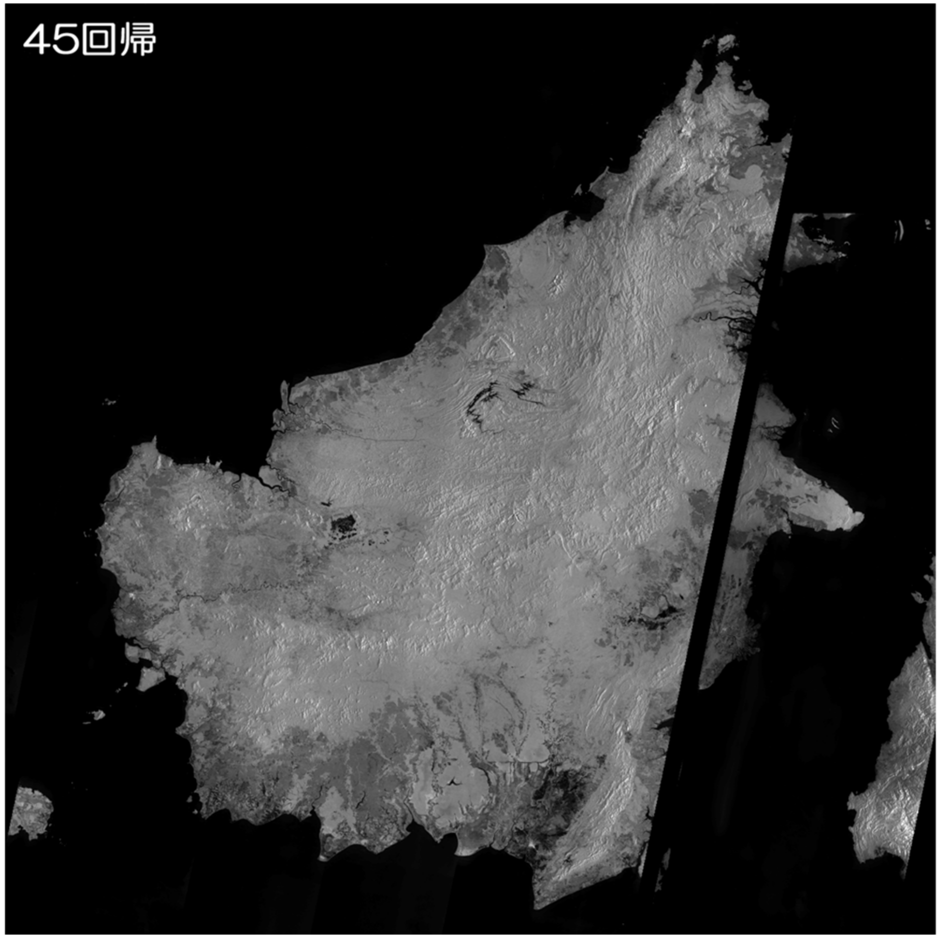
Machine learning

(Random Forest)

Above-ground biomass map

Case study: Forest above-ground biomass map development

PALSAR-2 time-series data

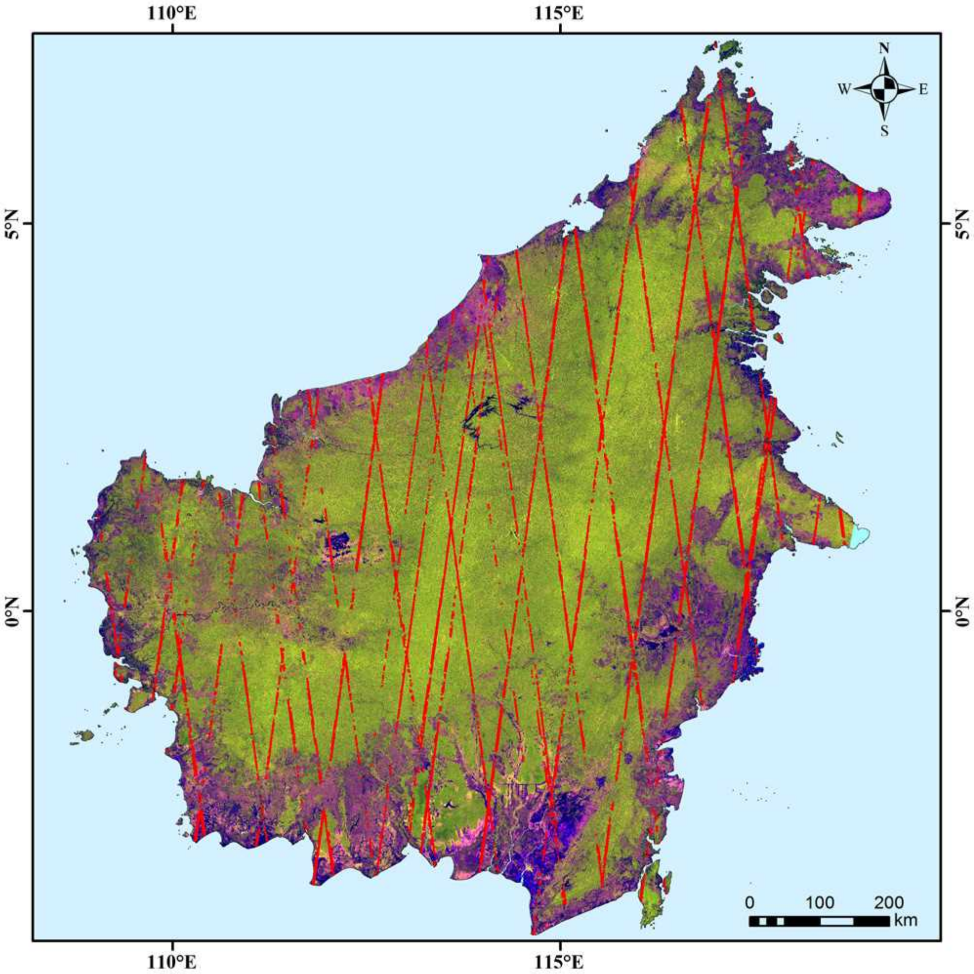


Data used:

- ✓ PALSAR-2/ScanSAR image
- ✓ HV/HH time-series image
- ✓ Acquisition: 9-times in 2016
- ✓ Spatial resolution: 50m

Case study: Forest above-ground biomass map development

Training/validation data



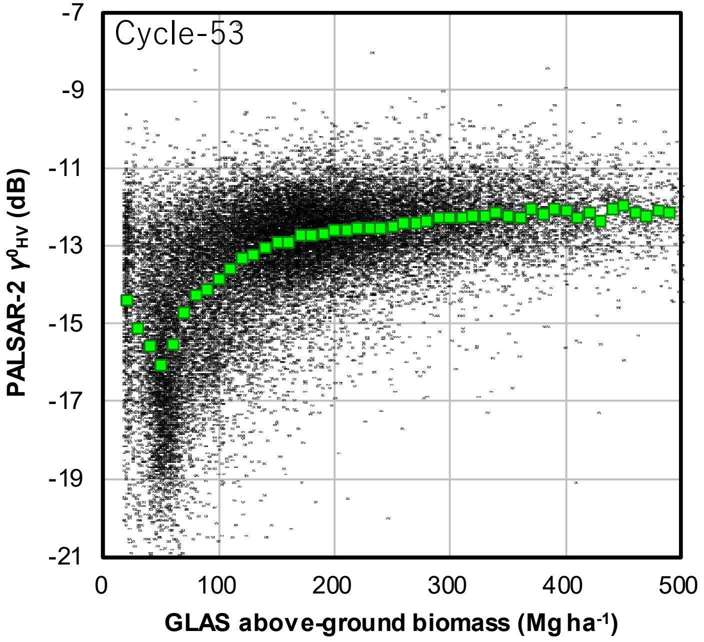
Data used:

- ✓ ICESat/GLAS
- ✓ About 80,000 footprints
- ✓ Acquisition: 2003-2008

Case study: Forest above-ground biomass map development

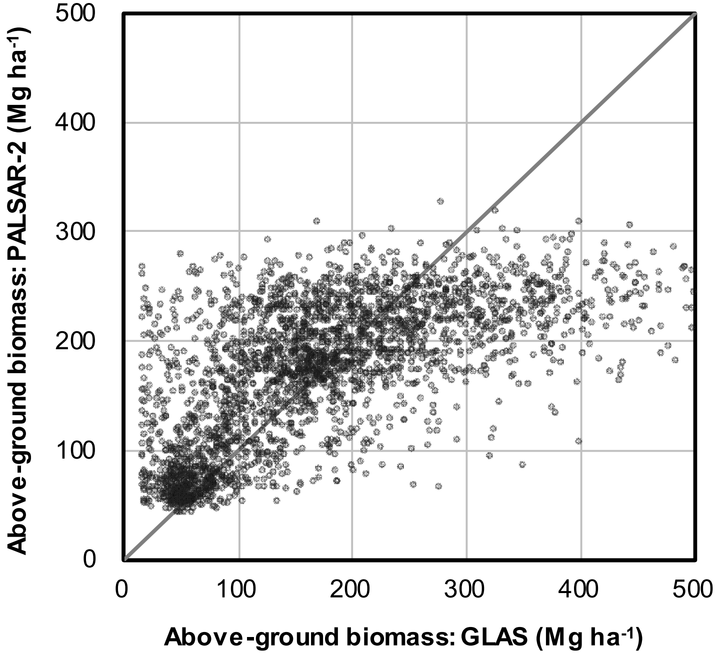
Validation of AGB estimation models

Single HV image



☐ Signal saturation points = 130-160 Mg ha^{-1}

Time-series data

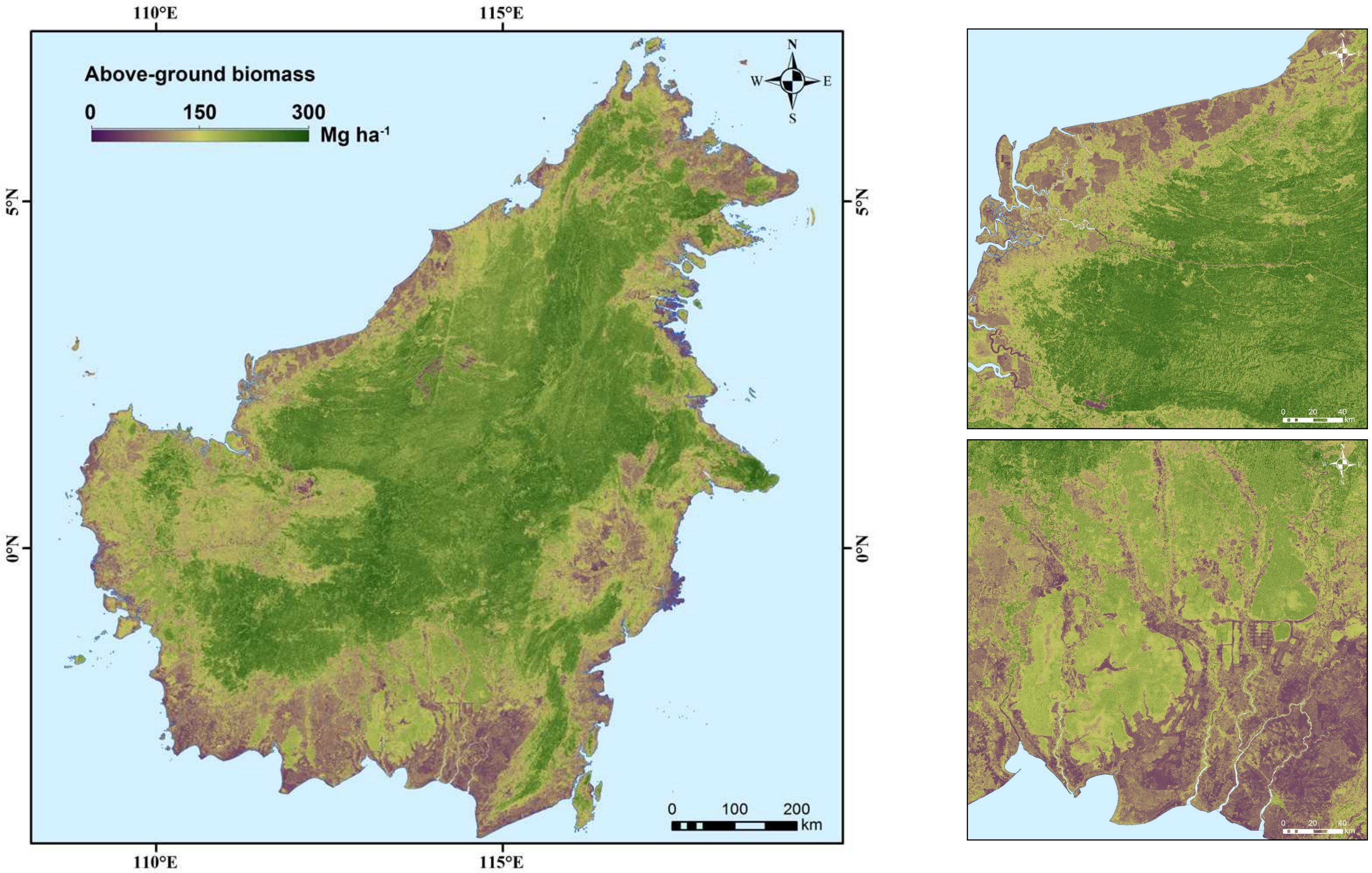


☐ Signal saturation points = 280 Mg ha^{-1}

☐ Root-measn-square error = 62.8 Mg ha^{-1}

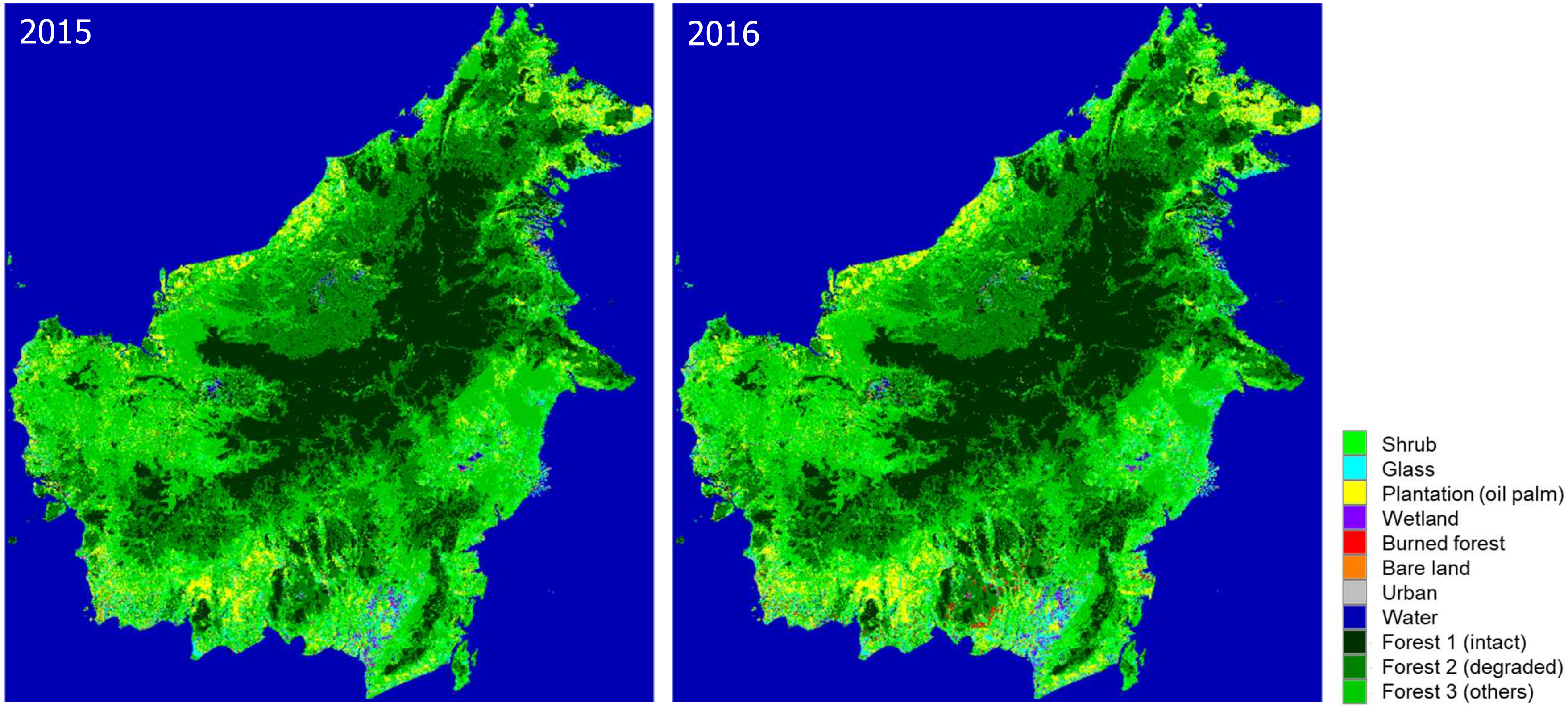
Case study: Forest above-ground biomass map development

Above-ground biomass map



Case Study : Land-cover map development and regional-scale carbon budget estimation

Land-cover Map



Accuracy (2016 map)

- ✓ User’s accuracy (forest): 91.2%
- ✓ Producer’s accuracy (forest): 80.6%
- ✓ Overall accuracy: 74.3%

Case Study : Land-cover map development and regional-scale carbon budget estimation

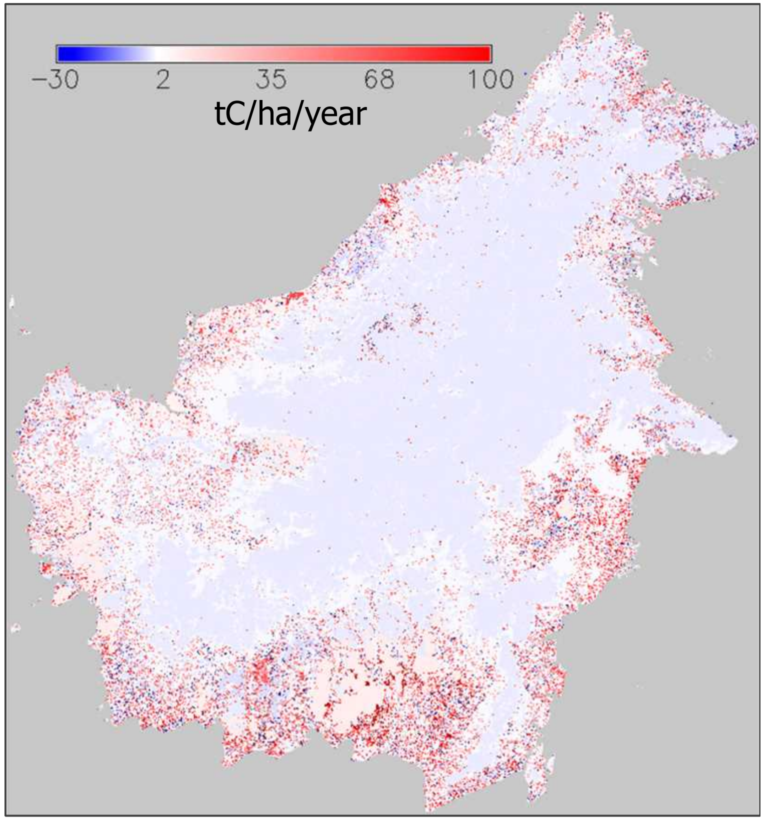
Area of each land-cover category

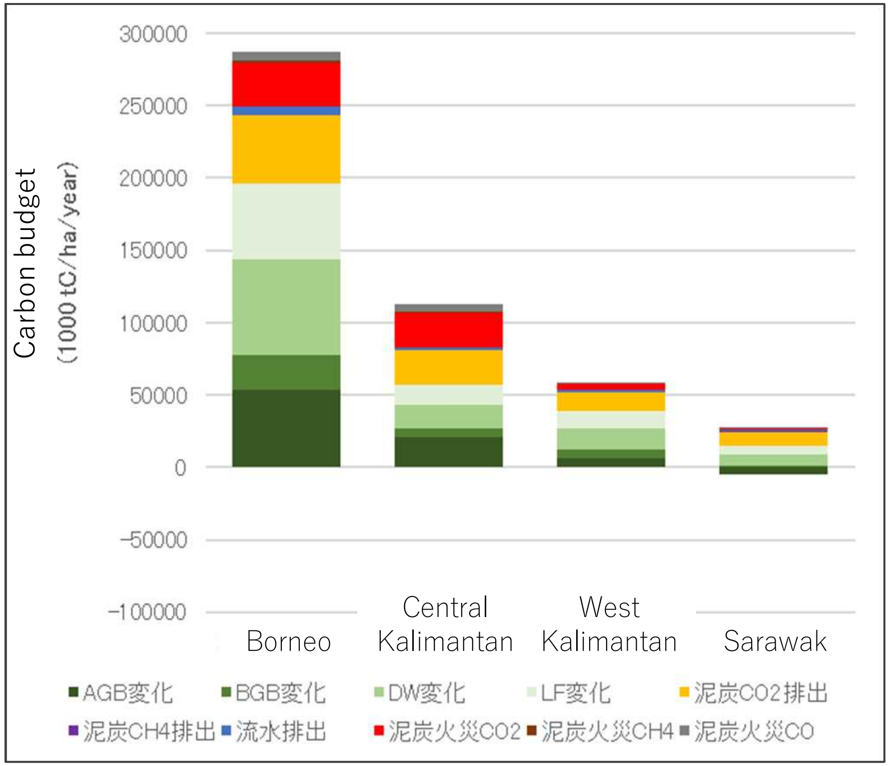
Unit: 1,000 ha

Area	Land cover category	All		Peatland			
		Year 2016	Year 2015	Year 2016		Year 2015	
Borneo	Intact forest	19936	20157	778	4%	802	4%
	Degraded forest	16025	16209	1678	10%	1727	11%
	Small/mosaic forest	18545	21744	1408	8%	1918	9%
	Shrub	11892	9935	1294	11%	1159	12%
	Glassland	3012	2330	414	14%	316	14%
	Plantation (oil palm)	4968	4359	1052	21%	841	19%
	Wetland	441	448	29	6%	26	6%
	Burned forest	329	88	141	43%	17	19%
	Bareland	457	356	23	5%	14	4%
	Urban	62	51	6	9%	3	5%

Case Study : Land-cover map development and regional-scale carbon budget estimation

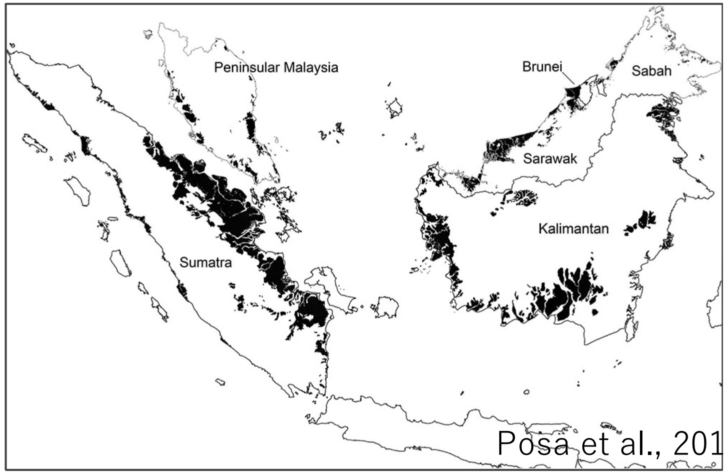
Carbon budget estimation: 2015-2016





Case Study : Peatland subsidence monitoring and local-scale carbon budget estimation

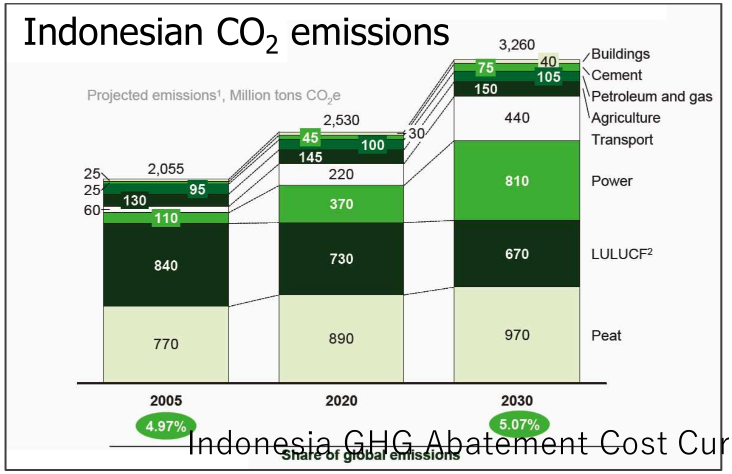
Peatland is a major carbon source in Borneo



Posa et al., 2011

Getty Images

ESA website

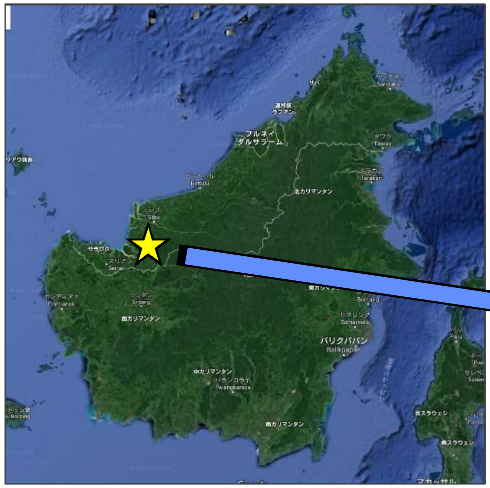


Indonesian CO_2 emissions

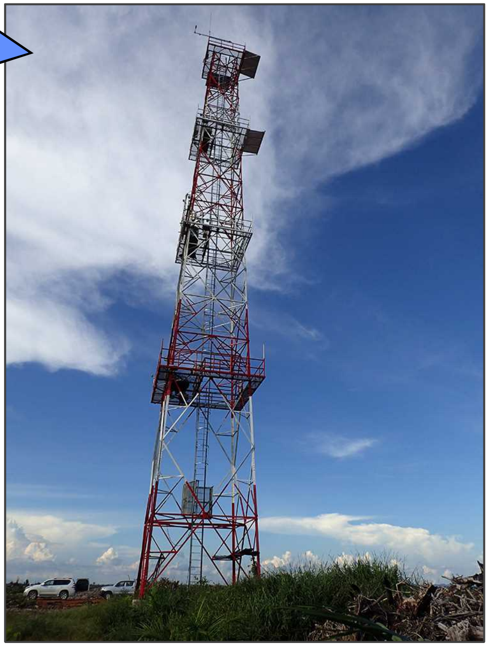
Indonesia GHG Abatement Cost Curve

Case Study : Peatland subsidence monitoring and local-scale carbon budget estimation

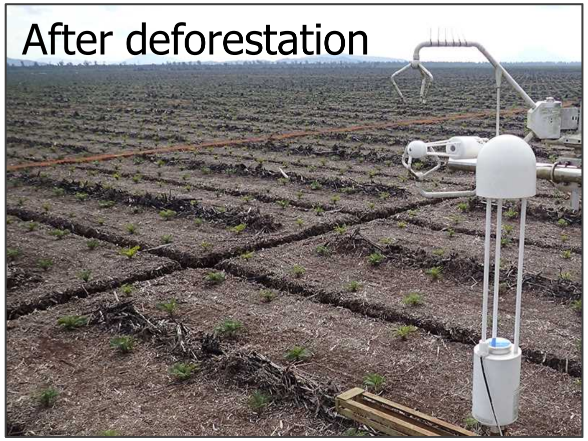
Study site: Peatland receiving development pressure



40m flux tower

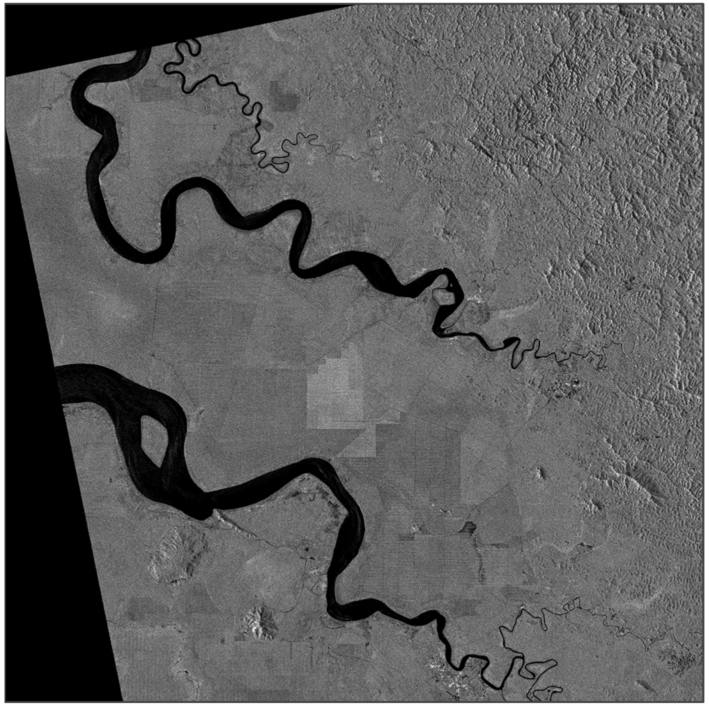


Provided by Prof. Hirano (Hokkaido Ur



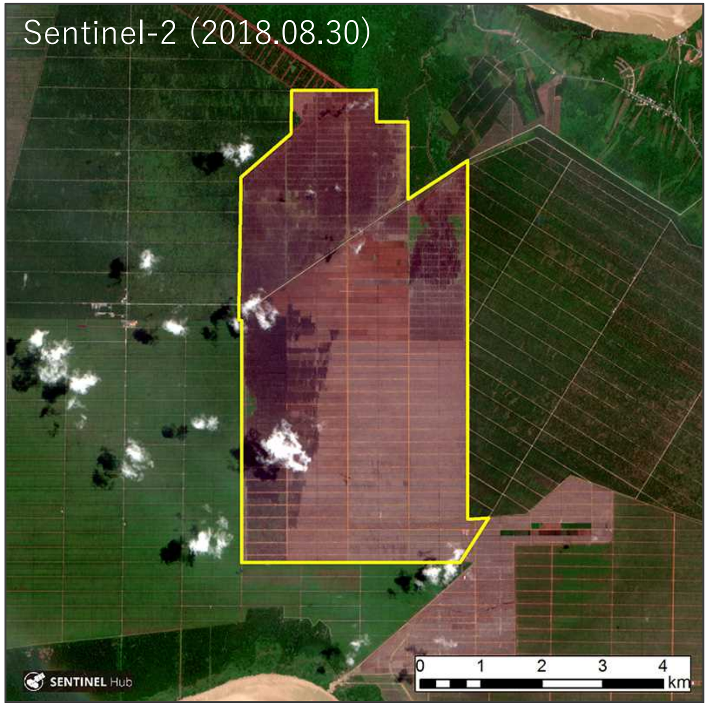
Case Study : Peatland subsidence monitoring and local-scale carbon budget estimation

PALSAR-2 data for InSAR analysis



Acquisition date: 2017.09.26
2018.01.30
2018.02.27
2018.05.22

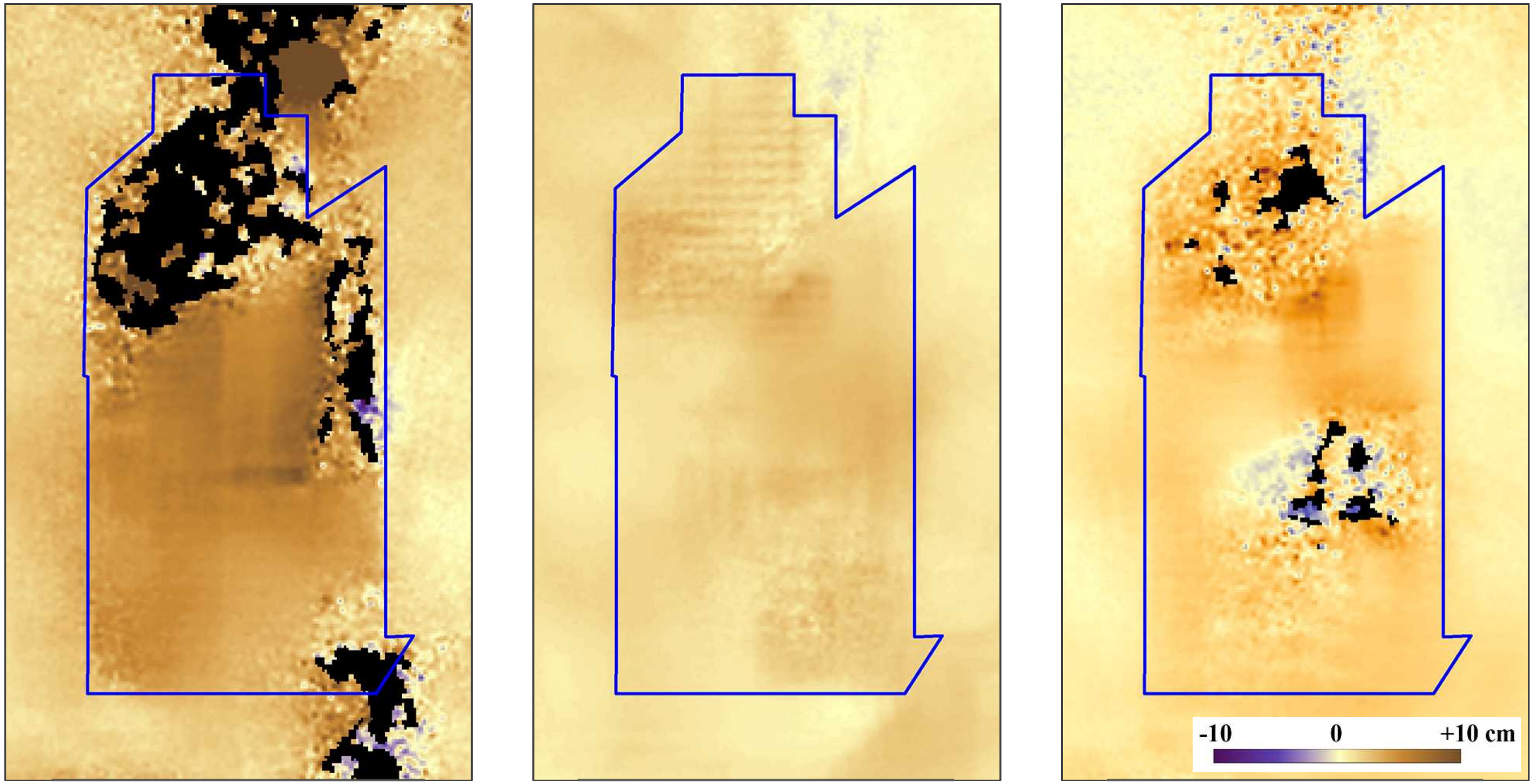
Target area for carbon budget estimation



Area: 2,630 ha
History: Deforestation in May and Sep. 2017
Oil-palm planting in Jul. 2018

Case Study : Peatland subsidence monitoring and local-scale carbon budget estimation

Ground displacement distributions in Line-of-Sight (LOS) direction



2017.09-2018.01

2018.01-2018.02

2018.02-2018.05

Case Study : Peatland subsidence monitoring and local-scale carbon budget estimation

Carbon budget estimation

InSAR pair	**Subsidence rate** (cm yr^{-1})		**Carbon emissions** (tC ha^{-1} yr^{-1})
	Average	Maximum	
Sep. 2017 - Jan. 2018	-16.3	-32.4	43.1
Jan. 2018 - Feb. 2018	-27.8	-66.1	73.5
Feb. 2018 - May 2018	-10.3	-44.2	27.3
Whole period	-15.0	-31.0	39.7

- Carbon emission = Subsidence volume × Soil bulk density × Soil carbon content
  × Contribution rate of oxidative peat decomposition to the whole subsidence

Summary and future plan

☐ PALSAR-2 time-series data has an ability in above-ground biomass estimation and land-cover mapping.

☐ PALSAR-2 InSAR technology has an ability to observe spatial distribution of ground subsidence in peatlands.

☐ These abilities are effective in carbon budget estimation in a large-scale.

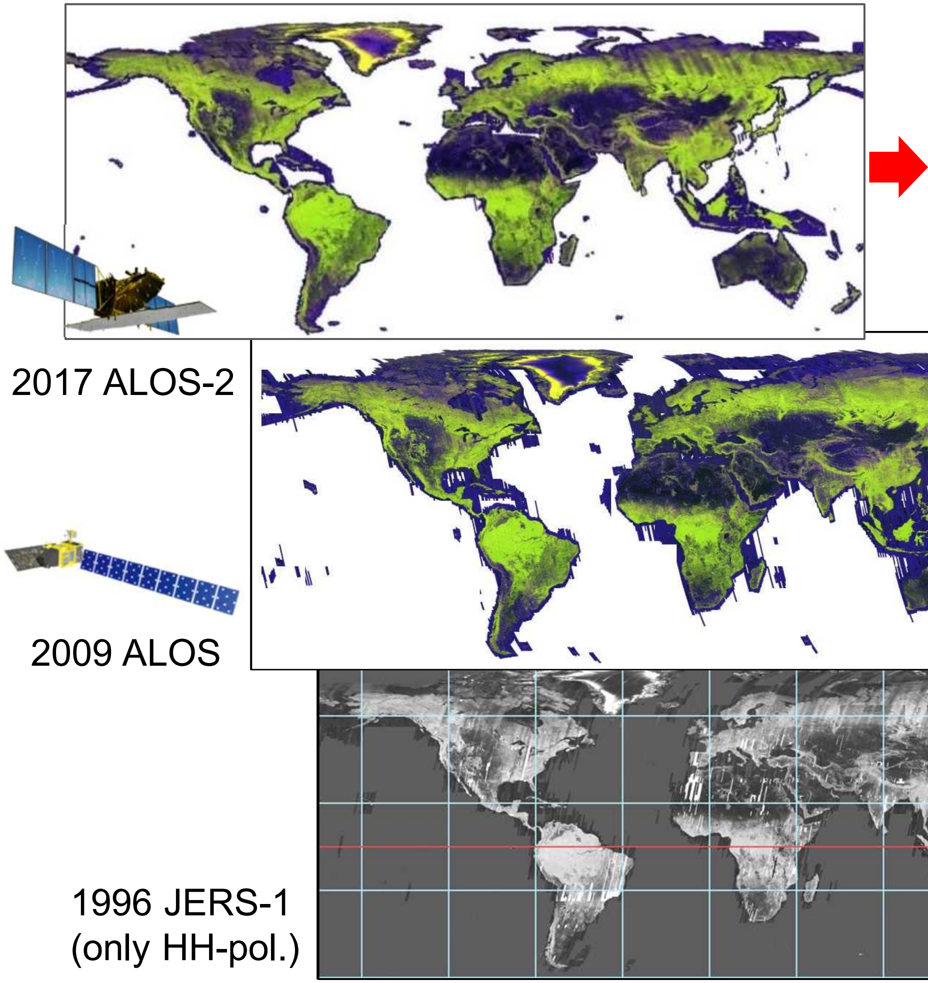
☐ In the future, we will compare in-situ observation data (CO_2 flux and peat depth) with our results to clarify the reliability of InSAR observation.

Peat depth observation pole
by The Sarawak Tropical Peat Research
Institute

Sustainable Forest Management:

Monitoring Forest Changes for More Than 20 Years

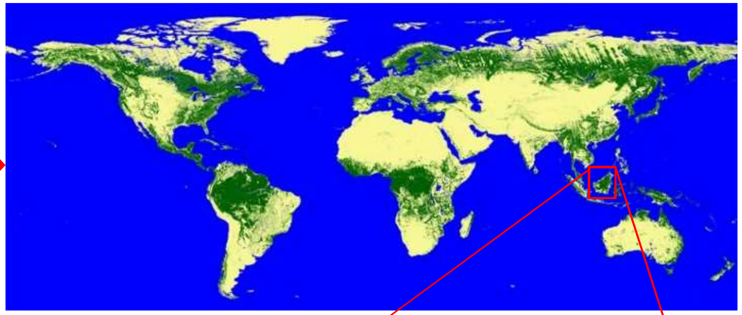
- ✓ JAXA has released annual global mosaic and Forest / Non-Forest (FNF) map by SARs
- ✓ JERS-1 (1996) ~ ALOS (2007-2010) ~ ALOS-2 (2014-2017) > Changes over 20 years



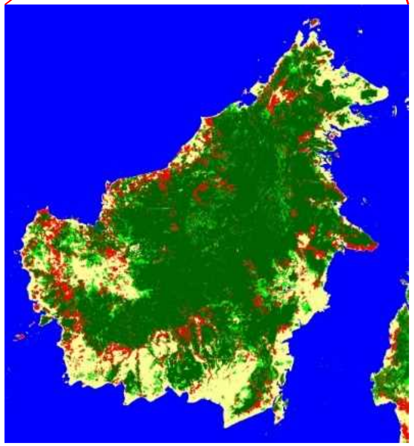
2017 ALOS-2

2009 ALOS

1996 JERS-1
(only HH-pol.)

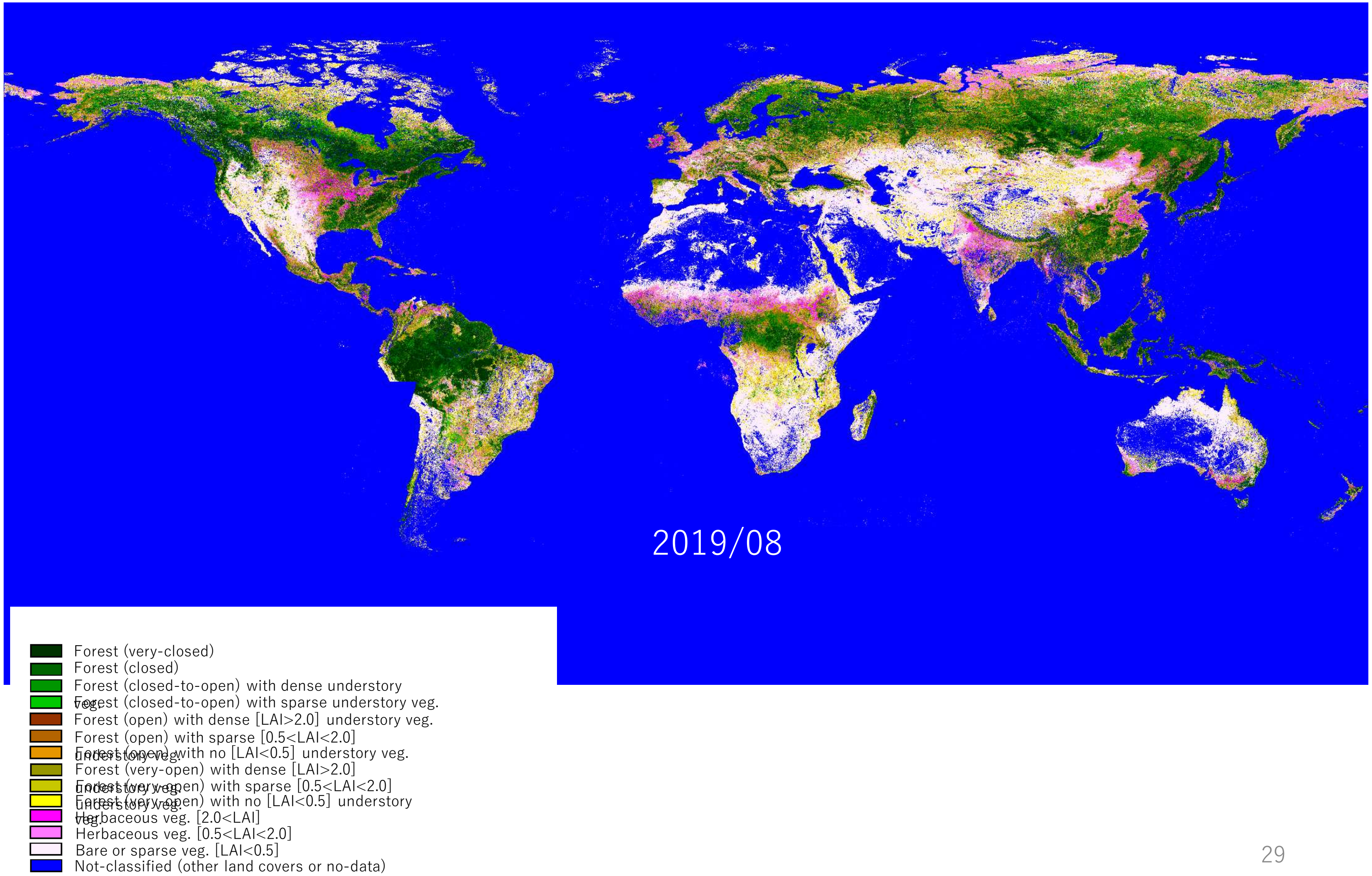


2017 FNF Map by ALOS-2



Forest change between 2008 and 2016. (red: deforestation, light green: reforestation)

GCOM-C SGLI Global land-cover map

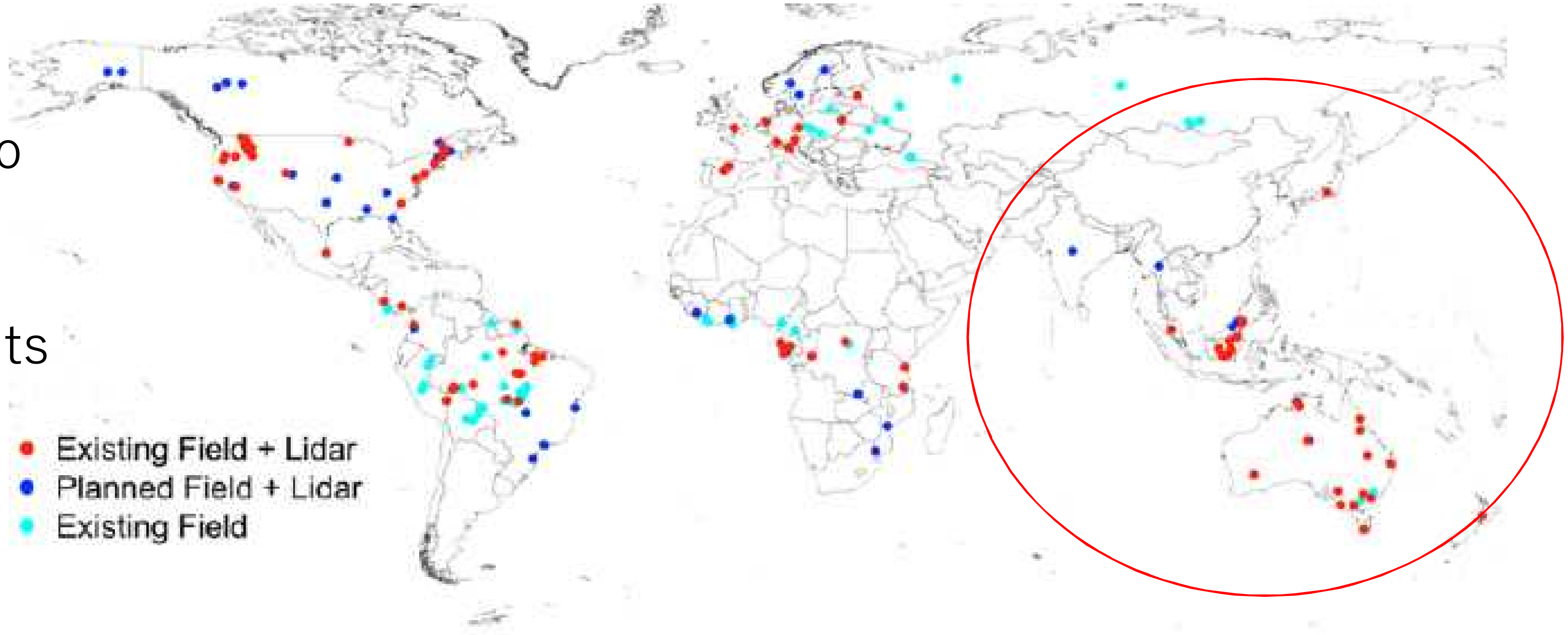


2019/08

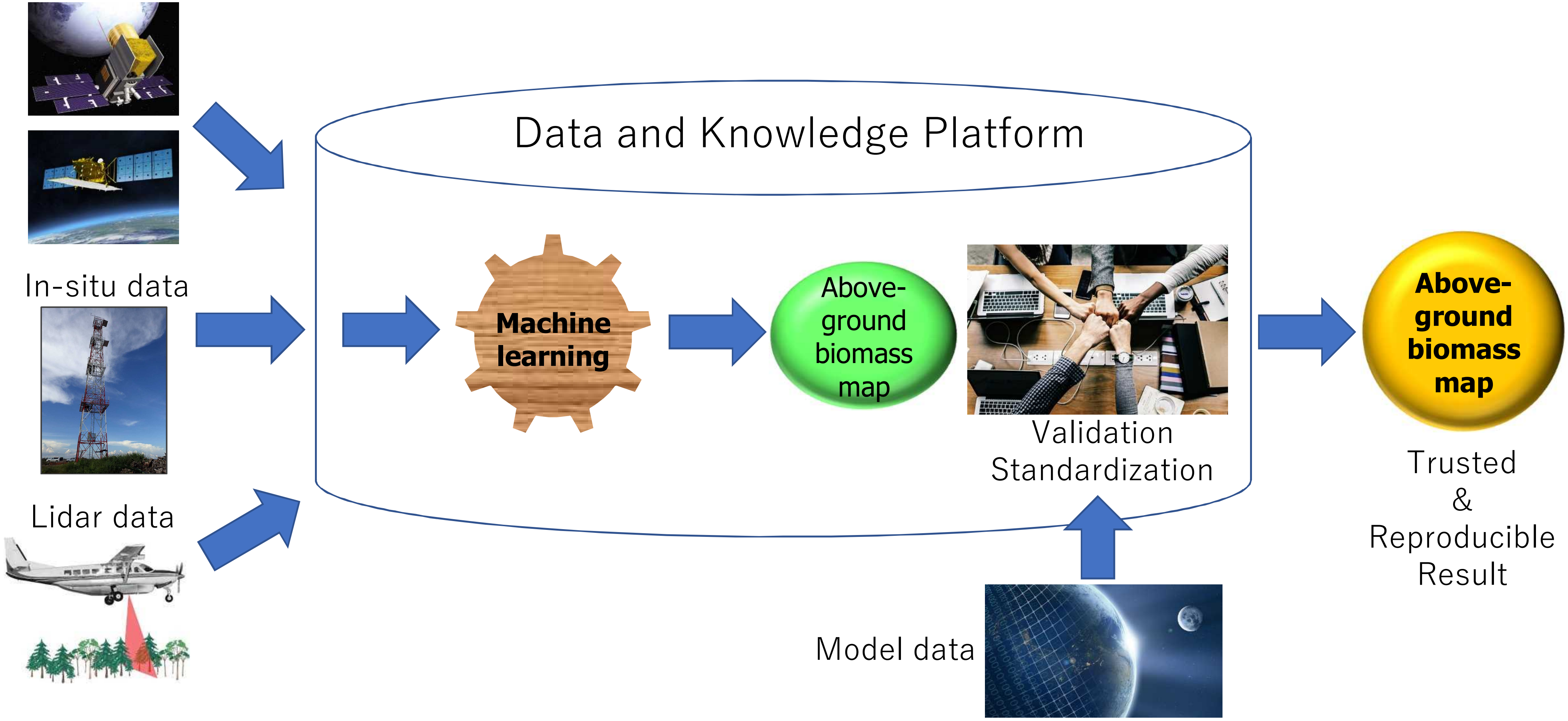
CEOS Land Product Validation (LPV) Biomass Subgroup

- To compile a list of LPV biomass supersites with high-quality longterm monitoring of forest aboveground biomass and existing, planned or logistically feasible airborne data.
- To develop a CEOS Biomass Protocol for methodological standardization.

ForestGeo
NEON
TERN
ForestPlots



Need data and knowledge platform(s) for collaboration



Satellite data

In-situ data

Lidar data

Data and Knowledge Platform

Machine learning

Above-ground biomass map

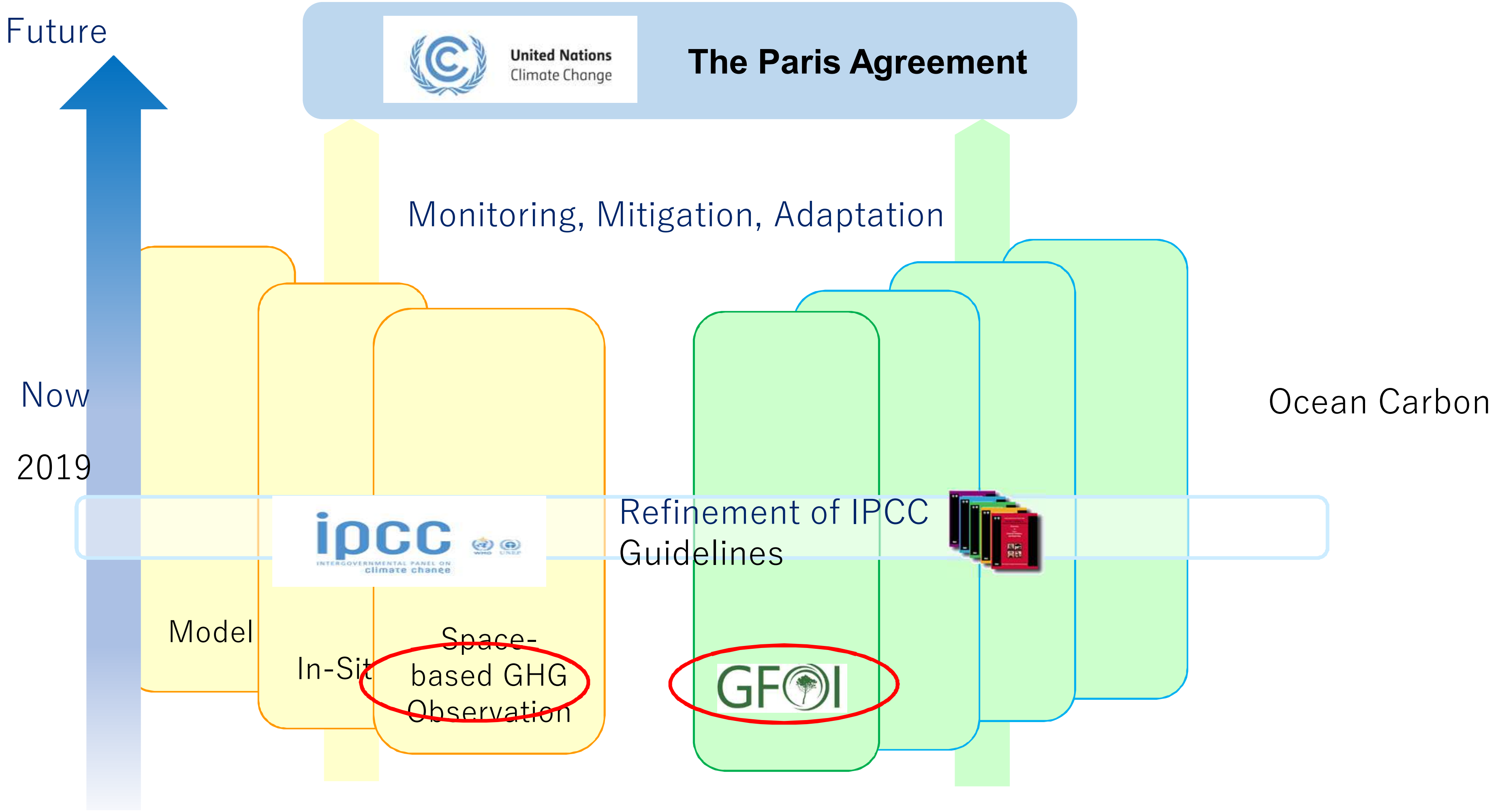
Validation
Standardization

Model data

Above-ground biomass map

Trusted
&
Reproducible
Result

Beyond Refinement of IPCC Guidelines



Future

The Paris Agreement

Monitoring, Mitigation, Adaptation

Now

2019

Ocean Carbon

Refinement of IPCC Guidelines

Model

In-Sit

Space-based GHG Observation

Discussion

- Earth Observation Satellite data can be coordinated by individual agency or through CEOS for data acquisition and provision
- In-situ would be more challenge but could be more instrumental in the GEO framework – how different In-situ networks can be facilitated and sustained in line with the GEOSS data sharing and management principles
- Integration between EO satellites and In-situ should be coordinated in the GEO framework as well – CEOS as EO Space Agency’s coordination body is ready to implement for GHG and Biomass cases and data and knowledge platform(s) is necessary to promote