**MINUTES**

## CEOS WORKING GROUP CALIBRATION AND VALIDATION LAND PRODUCT VALIDATION SUPERSITES AND BIOMASS VALIDATION WORKSHOP

### JAXA L-band SAR and ALOS-2/4

***Ake Rosenqvist (JAXA/soloEO)*** gave an overview of the JERS-1 SAR, ALOS PALSAR and ALOS-2 PALSAR-2 observations and the links between L-band SAR and biomass. ALOS-2 is currently in an extension phase in order to ensure that ALOS-2 is in operation at the same time as ALOS-4. The duty cycle has been reduced from 50 % to 30 % so only one coverage per year at fine spatial resolution will be provided in the latter years of operation ScanSAR observations will be undertaken 9 times per year for the entire tropical belt. Further revision of observation priorities and coverage is foreseen.

JAXA is increasing releasing data at no cost. The JERS-1 SAR data are available and the ALOS PALSAR data (Fine Beam + ScanSAR) will be publicly available from around April to June this year. The ALOS-2 PALSAR-2 data (ScanSAR) will be made publicly available also in 2020.

ALOS-4 is an enhanced version of the ALOS-2 and scheduled to be launched in JFY (Japanese Fiscal Year) 2021 (April 2021 - March 2022). ALOS-4 PALSAR-3 has a 14 day repeat and there is the capacity to do interferometry with ALOS-2. The swath width has been repeated from 100 km for Quad-Pol (i.e. fully polarimetric) and 200 km for the Dual-Pol with maintained ALOS-2 ground resolution. The ScanSAR will have a 700 im swath and the spotlight will be 35 x 35 km.

NISAR will also be providing observations globally at 10 m in dual polarisation every 12 days. This observation strategy is very similar to Sentinel-1 C-band and the data will be open and free. There is an opportunity here to use the ALOS-4 data in combination with the NISAR, and there is particularly potential in the fully polarimetric mode (e.g., for discriminating tree species). The 700 km swath width of ALOS-4 will provide a potential capacity of 3-6 observations every 2 weeks.

### MOLI

***Masato Hayashi (JAXA)*** gave an overview of the MOLI (which means forest in Japanese). Currently scheduled for launch in JFY 2023. MOLI has an optical imagery and a LIDAR. The LIDAR has 2 beams, split from one beam. The footprint radius will be 25 m and the spatial resolution of the optical sensor will be 5 m, with an image swath of 1 km. Airborne LIDAR experiments have been conducted in Japan for six areas in central Japan. Variables which were considered including Lorey's height, maximum height, stem volume and above ground biomass (AGB). Four products are envisaged with these being image and waveform data, canopy height and biomass, canopy height and biomass map and a further height and biomass map generated using other satellite sensor data (including PALSAR-2). A waveform simulator has been developed using a combination of LIDAR waveform and in situ biomass data. Ibaraki Prefecture was selected as the core site for algorithm development. JAXA have developed a prototype model to estimate AGB for cedar plantation forests, with this based on multiple regression and using waveform parameters such as relative height. The RMSE was 31.2 Mg ha$^{-1}$ ($R^2$-0.59) in the example given. Ground data were collected in cooperation with the Japanese Association of United Forests and there are also sites in Southeast Asia and would welcome collaboration with CEOS LPL and other international groups and organisations in the MOLI algorithm development.

**The GEDI Mission**

***John Armston (University of Maryland)*** indicated that the GEDI was launched to advance information on ecosystem structure and dynamics, including carbon cycle science and biodiversity. GEDI was launched in December 2018 a dn was fully commissioned on the 18th April 2019 and first data were released in January 2020. Science operations occur for 2 years and then there will be a wrap up and extended science phase. The footprint is nominally 25 m and a number of metrics including RH100. GEDI has three lasers split into four beams. The four coverage layers penetrate up to 95 % and 4 power lasers are used to penetrate 98 % of the canopy. There is 1 600 m spacing between and 60 m spacing along. The LIDAR measurements in the first two months initiate global up to about 55oN. A lot of processing is needed to claisyf cloud, noise and ocean returns. Australia is well covered but more information will become available for Tasmania, which is less well covered (as an example). There are some areas (e.g., China, Amazonia) where there is a lot of cloud and noise. The resulting data can be used for biomass estimation. 1 billion usable shorts have been acquired and every month, more and more data are delivered, with 42 m spots every month. After 3 months, GEDI provided more than two orders of magnitude more shots that ICEAT provided for similar biomass studies.

Data are processed to canopy height and ground level elevation, including canopy cover, LAI and vertical foliage profile and also above ground biomass. GEDI can also be used to support habitat and biodiversity models and can be used to improve height and biomass estimation. The Level 1-4 products were listed (and are described above).

Height and structure metrics have been released in the first two months and subsequently on a monthly basis (from February 2020). In September 2020, the biomass gridded products will be released and these will then be released monthly. Transects of measurements, including the ground elevation, will be provided or can be constructed. The Level 2 biophysical products released along transects include the vertical profile. Surface elevation products have been generated from LIDAR, which can be used to generate global topography as well as canopy height.

For estimating biomass, about 80 % of the 1 km cells will meet an accuracy within 20 % of the standard error or 20 Mg h10, whichever is greater and subject to instrument availability. The standard error of biomass at 1 km resolution will be provided. A number of simulated datasets have been generated along the ground data and considerable effort has gone towards data sharing and use agreements. An overview of the number and size of plots was also provided. Over many of the GEDI sites, there are more ALOS data and this has been useful for tracking performance. The majority are in the US. Cover, height and geolocation area all assessed and offsets are small (< a few metres). New campaigns have been conducted in the US and central America and underflights have been undertaken along the GEDI tracts. LVIS data have been acquired over many sites. Similar campaigns are also being considered (e.g., Gabon in Africa).

In summary, GEDI continues to operate normally and is considered to be a success. First datasets are available on the DAAC. Feedback is welcomed. The first AGB maps will be generated by September 2020. The database will continue to expand and new airborne campaigns are planned. The laser life is 6 years but continuation requires positive feedback on future requirements.

**NISAR**

**John Armston** continued with the NISAR mission. NISAR is an L- and S- and 12 day orbital repeat left looking only mission (ascending and descending phases, so effectively two observations every 12 days). 240 km swath using SweepSAR. Fine resolution 10 m resolution will be delivered at L-band dual pol. Launch is expected in May 2022. The aim is to estimate global above ground biomass up to 100 Mg ha$^{-1}$ at 1 ha resolution with an accuracy of 20 Mg ha$^{-1}$. Biomass will only be estimated over the calibration and validation sites. There are different acquisition modes for different science targets. Quadpol data will be collected over Illinoi, Michigan, Ohio and parts of Alaska. S-band coverage will focus on India. Coordination between the GEDI and NISAR as well as other missions (e.g., BIOMASS) is ongoing, with the GEDI providing opportunities for extending the saturation beyond 100 Mg ha$^{-1}$.

There are a number of CAL VAL sites for NISAR and there are independent sites for post launch calibration. No data agreements have been developed for data sharing. The ATBD documents for NISAR are complete. There will also be a soil moisture global product. A number of airborne sites have been collected to support NISAR and all data are available. ISRO has also conducted research flights in India. More information can be found at https://nisar.jpl.nasa.gov.

**Land Product Validation Supersites**

***Fernando Camacho (EOLAB/PCUV)*** introduced the LPV supersite concept. He noted that valiation was crucial to maximize the return of investment of satellite missions by providing the user community with the EO products with the associated uncertainties. The LPV mission is to increase the quality and efficiency of global satellite product validation and coordinate quantitative validation of satellite -derived products in a traceable way. The LPV vision is that land product algorithms are iteratively improved based on validation results. Reliable uncertainty information is only determined through community agreed good practices for validation.

The objectives of the group are to foster and coordinate quantitative validation of global land products, increase quality and efficiency of validation through establishment of international stands and protocols and provide high level ground data. A number of protocols have been established including LAI, land surface temperature and surface albedo. The AGB protocol is being developed currently.

Validation is the process of assessing by independent means the uncertainty of a derived product. Generally, it relies on ground reference data and should be representative of global conditions. Fiducial reference measurements with uncertainty characterization are needed.

Validation has traditionally relied on sites which are independent from each other. Some agencies have theie own networks of sites and there are also ad hoc campaigns, such as for the FLEX mission. The supersites need to be sustainable and these can be complemented with other sites or through specific campaigns. A CEOS CalVal action was conducted to evaluate the land validation supersites and ensure consistency between different variables.

A supersite needs to be super characterised in terms of canopy structure and geo-physical variables, be active with long term operations and be supported by LIDAR and hyperspectral sensors when possible.

- **TERN** includes biodiversity, phenology, LAI, inventories, AGN and terrestrial laser scanners. There are also protocols and free data access. The above ground biomass library was also mentioned.

- **NEON** coordinates standardized ground and airborne datasets and has a wide range of observations.

- The **ICOS** Ecosystem Thematic Centre provides information on vegetation and other land surfaces.

- **LPV** members also has extensive collections of data.

All of the information can be obtained from https://lpvs.gsfc.nasa.gov. The evaluation is based on long-term operations, freely accessible, well-characterised 3D structure, measurement of at least 3 variables, protocols available and supported by airborne and drone sensor data. Several sites are providing AGB estimations. Improvements include spatial coverage, uncertainty characterisation, QC/QA and interoperability.

Examples of sites include Whytam woods in the UK (near Oxford), Tumbarumba in Australia, and Santa Rosa in Costa Rica.

**There is a need to revise the current state of supersite networks and plans, identify new potential sites and update, and evaluate potential use for biomass estimation. There is a need to discuss measurement protocols, data and metadata formats and data access, uncertainties and AQ/AC.**

**TERN ecosystem processes**

***James Cleverly (UTS)*** gave an overview of TERN and the NCRIS, which funds TERN. TERN is a distributed network with various activities occurring across the continent. TERN focuses on biodiversity, carbon and water and land and terrain. Three platforms support these, which are landscape assessment, ecosystem surveillance and ecosystem processes, with these increasing in detail but often decreasing in spatial resolution respectively. The research infrastructure includes monitoring sites, eddy covariance towers and cal/val sites.

Ecosystem surveillance is particularly charged with collecting a range of data including, LAI, soils and DNA. Landscapes focus on remote sensing, soils and terrain. Infrastructure includes permanent plots, phenocams, photo plots etc. A key element of TERN is to integrate these different datasets. An example is Australia's Mangrove Observing System. A national environmental prediction system is also available with this including citizens, industry and government. For information, see TERN Environmental Research Letters 14 (2019). TERN has a number of supersites distributed throughout Australia and many of these are multi-institutional.

Ecosystem processes is based on assessing the drives of changes in ecosystems, with this including flux towers, other sensor data (e.g., acoustic soundscape, phenocams) and classical field surveys (e.g., biomass, LAI). Physical access to researchers is provided by CSIRO's COSMOS, LIDAR (through TERN landscapes and NCRIS groundwater), GBOV and sites specific infrastructure.

AGB, NASA ECOSTRESS and NASA SMAP are also focusing on satellite cal/val and global outcomes. For more information go to tern.org.au.

**NEON**

***Phil Townshend (University of Wisconsin)*** outlined NEON, which is funded by the US National Science Foundation. NEON is a funding mechanism for 30 years which has 81 sites across 20 ecoclimatic domains. Includes field observations, airborne data and flux towers and these are distributed throughout the US. In each domain, there are core and relocatable aquatic and terrestrial sites. The domains were quantified through cluster analysis of climatic and soil variables across the US. Core sites were selected within the spatial centroid for each domain and relocatable sites were selected to represent scientific questions of interest within each domain.

For the field sites, airborne data are collected at least annually and there are 1818 data products spanning decades and standardized across sites. The airborne platform has an imaging spectrometer, LIDAR (both waveform and discrete returns) and high resolution imaging camera. Emphasis is on obtaining structural information across 10 x 10 km sites. The imaging spectrometer is a duplicate of AVIRIS, which measures 380-2510 nm. The digital camera sensor provides a stand alone product, which is used primarily for context. The aim is to fly at peak greenness (from MODIS) across each of the domains and for all 10 x 10 km sites, with this ensuring consistency between annual collections. North-south lines are flown. The return frequency of acquisitions varies between sites, ranging from Puerto Rico (1) to the northeast US (5).

The concept is to use these data to focus on energy transfer, metabolic regulation, phenology, community dynamics and biogeochemical cycles. A TOS sampling schematic was presented, with these include flux towers, biodiversity sampling and plot-based measures (generally nested). For biomass, information on individual trees (DBH, height, crown dimensions) is collected and these can be scaled using airborne data using, for example, machine learning. A number of products (with ATBDs) are provided including ecosystem structure and are distributed for free (go to NEON data website). The intent has been to produce AGB data but the maps are based on remote sensing equations from the literature and so are not yet well vetted. There are not many staff working on the overall dataset but a substantive number working on data collection. Examples were presented for Jones, UnderC, Konza and Talledaga, with these presenting forest and prairie sites and for which algorithms have been developed to retrieve LMA, nitrogen, phosphorus, carbon, chlorophyll and phenolics (see Wang et al., in review). Airborne data are free and are corrected using HyTools and allow these data to be more consistently used. Most people are working with the discrete return rather than waveform data and there has not been particularly good penetration of the denser forests.

None of the sites are owned by NEON and so some data permissions might be needed.

**Japan's activities and plans for biomass supersites (JaSForB & JSS500).**

***Masayoshi Takahashi (FFPRI) and Kenlo Nasahara (Tsukuba University)*** explained how they are addressing effective use of satellite images in forestry, particularly in relation to climate change. The Forestry and Forest Products Research Institute was founded in 1905 and is funded by the government. They referred to the REDD+ Cookbook and associated Annex. The Japan Association of University Forests (since 1951) consists of 27 universities and the university forests have permanent field plots that measure above ground biomass. Many of these forests are also associated with airborne LIDAR, aerial photographs and other thematic datasets. University Forests is helping to make a forest biomass map for Japan and this is associated with a cloud-based open and free platform.

As an international action for biomass research, there is an interest in linking with the MAAP and CEOS, both using and contributing data. They also mentioned that their focus was generating a biomass map for East Asia but also globally.

JAXA has a network of supersites (JSS500 - JAXA Super Sites 500). These are 500 x 500 m in area, homogenous and occuring on level (flat) terrain and they can provide validation for multiple satellite sensor AGB retrieval algorithms. The sites cover a range of biomes, both in Japan and also internationally (e.g., Mongolia). Data collected include AGB, LAI and fAPAR, which are already being used within the GCOM-C land products. The 500 x 500 m was selected to allow for the different resolutions and geolocational accuracy of the various satellite missions. Sites are in areas that are the most cloud free, are easy to access, have good facilities and strong collaborations (e.g., with field ecologists). Within each site, flux tower measurements, tree census data and biophysical measures (e.g., LAI) are provided) and automated and continuous measurements as well as terrestrial laser scanner measures are taken. Target accuracies for in situ observations are also provided (typically < 5 %). Airborne LIDAR is essential for scaling observations. In Biomass Protocol draft noted a number of challenges including land access, remote sensing and ecology differences, protocols etc. and called for more simpler English and grammar use to accommodate also non-native English readers.

**Copernicus GBOV: Contribution to EO vegetation products validation I.**

***Christophe Lerebourg (ACRI-ST, France).*** Many partners are providing ground data. The Copernicus project is providing > 20 products on an operational basis. GBOV aims at faciliting the use of observations from operational ground-based monitoring networks and their comparison to Earth Observation products. GBOV is on the global component of the Copernicus land surface website. Information is provided on Leaf Area Index, soil moisture, albedo, land surface temperature, fAPAR and so on. GBOV applies upscaling procedures, which allows validation of EO products. There are 57 sites around the globe, mainly in Europe, the US and Australia. The EU wanted a long time-series of at least two years and this is why there is less of a global representation. There is a need for more near real time data.

Focus also is on installing new infrastructure and to upgrade existing sites. For vegetation, there will be a PAR network and automated hemispherical camera (on the Hainech site), field visits (at least 12 per year) with LAI (LiCor) and Digital Hemispherical Photographs. Continuous land surface temperature measurements are also been recorded. The infrastructure varies between sites. This year, Litchfield (Australia), Dahra (Senegal) and Sukuza (South Africa) will be upgraded or new instrumentation put in place. A similar suite of instruments will be installed. As a result of these new upgrades and sites, the overall network will be enhanced so that it has representation in other regions (e.g., Africa), although the global coverage is still lacking. All data are freely available and accessible on the GBOV portal, which now has over 300 users. The data providers are acknowledged including in peer-reviewed articles. Strengths and weaknesses were summarized. Strengths include international collaboration, consistent formats, upscaling. Weaknesses include lack of near real time measurements, full geographic representation and longevity.

**Copernicus GBOV: Contribution to EO vegetation products validation II.**
***Luke Brown (University of Southampton)*** highlighted that existing data (e.g., DIRECT 2.0) cover many sites and vegetation types and provide data from the early 2000s. However, most are individual campaigns, few site cover the phenological cycle, there are some methodological inconsistency and limited data to validation products from new sensors. New environment monitoring networks provide an opportunity to complement existing datasets.

In GBOV, FAPAR, LAI and FCOVER are the main vegetation parameters being covered. The data are useful for Copernicus but are useful for other products. Component 1 has focused on sites and data availability with focus on the NEON sites in particular. 20 sites are considered, with these representing those that are occurring across the US. Digital hemispherical photography represents a major data collection mechanism and these are provided as raw images. These are being processed in GBOV to provide useful parameters. Information on the overstorey and understorey are being developed as more relevant to Earth observations. The photographs are used to calculate LAI, FAPAR and FCOVER. Quality flags are also provided, with these based on visual inspection. There are over 4000 reference measures (in situ) in the database. These then need to be upscaled using empirical transfer functions, with this based on the CEOS WGCV LPV. Temporal scaling and radiative transfer modelling are also being considered. Comparisons with actual satellite sensor data indicate a strong consistency and high performance over time. An overview of instrumentation at the various sites (e.g., Tumbarumba and Litchfield in Australia, Hainich NP in Germany, Wytham Woods, UK, Valencia in Spain, Dahra in Senegal).

See Brown et al. (2020). Tracking forest biophysical properties using digital repeat photography: A fisheye perspective using digital hemispherical photographs from below the canopy. Agriculture and Forest Meteorology, 297.

**Long term Ecological Sites**

***Micahel Mirtl, Co-chair of ILTER***. Explained the scientific motivation for eLTER RI, the design, status and assets, global embedding and links with TERN and the outlook for satellite cal/val support. Has a broad remit and the aim is to consider the evolution of ecological systems and their transformation associated with human land use but also climate and also their functionality in the long term. Addresses multiple scales, downwards and upwards. The approach is cross-disciplinary, encompassing a range of layers, and serves many research communities. eLTER provides basic site infrastructure, data notes integrating baseline observations of EEVs, multiple other data sources, user access to data and site access. Considers inputs, outputs and ecosystem change, looking at system structure and functions, main drivers of change and interactions of slow/fast disturbance effects. There is also association with atmospheric and hydrological experiments/observations. Focusing on overarching research questions which have a wide range of data requirements, with consideration given to specific processes and controls, ecosystem types and site specific modifications. eLTER considers abiotic heterogeneity, biotic diversity, socio-economy, energy, water and matter budgets and tries to link this information to address processes and events. Refer to Mollenhaue et al. (2018) Science of the Total Environment, 624, 968-978. In the eLTER RI Observation of Ecosystem Integrity, biomass (stand height, tree diameter, litter fall and above ground biomass are included. eLTER Plus ks looking at the calibration/validation needs driving variable/method selection and the use of RS data as a contribution to the eLTER information cluster. ELTER has the ambition for harmonization and accessibility of legacy data from various sites and a data integration portal has been opened. Other portals were mentioned including the Life Project. eLTER is a component of the IILTER. Refer to **https://deims.org** to access information on the 150 sites of ILTER. eLTER also has substantive stakeholder support, coverage and representivity.

Finally, it was noted that fiducial reference measurements for vegetation must have metrological traceability to SI, full uncertainty budget, consideration of spatial/temporal scaling issues etc. These criteria are linked to the different sites. The eLTER implementation time plan was displayed and goes to 2032 at least.

**Earth observation, climate and optical group**

***Joanna Nightingale (NPL). QA4E.*** Enables assignment of quality metrics on EO data and derived information facilitating a global interoperable EO/climate observing system. Feeds into climate models and policy decisions. Considers pre-flight and post-launch calibration, NPL has won TRUTHS, which will take the calibration facilities at JPL and put into space. It is a hyperspectral imager that is climate-dedicated and provides traceability in space to SI units and enable in flight cross calibration to SI standards - so calibration happens in space and on the fly.

Data and derived products need a fully traceable indicator of their quality but this is rare for satellite data and no regulatory frameworks (Nightingale et al., 2018; 2019). Currently, there is an under-investment in coordinated cal/val infrastructure and methods. This creates a reliance on reference networks that are not specifically designed or focused on the specific challenges of the satellite data. Existing sites/in situ campaigns are ad hot, often one off, measurements are inconsistent and there is lack of spatial and temporal relevance.

Many products do not have a meaningful way of assessing measurement errors and bias. So, NPL is looking at conformity testing, aiming for end-to-end traceability within all projects.

frm4veg is focused on establishing protocols for traceable in situ measurements of vegetation related parameters to support satellite product validation. Focus is on surface reflectance, FAPAR and canopy chlorophyll content (CCC). Outputs are lab and field protocols for the calibration of instruments. Initial satellite product validation methodology guidance will be provided. Supersites include Wytham Woods and Valencia. Activities include test measurements (e.g., Origo et al., 2020), with consideration given to site location, sky conditions, spectralon panel correction and hot-spot and non-nadire effects). NPL are also looking at reference datasets and procedures and the factors that influence observations.

In Phase I, consideration will be given to UAV hyperspectral validation and then will work on community agreed methods for fAPAR and CCC. Field campaigns will also be conducted in continental Europe and will focus on sites with other mission or cal/val work. A surface reflectance round robin exercise will be hosted at one site in the summer of 2021. Workshops are designed to connect and align the international community. Differentiated between ca,[aogm and permanent FRMs, with these ensuring that sites are suitable for satellite calibration/validation.

**Data and metadata harmonisation - TERN approach**

***Gerhard Weis, Solution Architect.*** Introduced TERN, the requirements and approach. TERN's purpose is to ensure a national infrastructure for research data. TERN focuses on a wide range of topics, such as land cover dynamics and phenology, acoustic sensors etc. There are more than 600 ecosystem observing sites and over 2500 datasets. TERN is trying to find one access point for all data and making data discoverable and accessible. This is essential to serve a wide range of users. Objectives include providing an integrated platform for plot-based ecological data, including a scalable platform, an integrated view and support of data exchange. Although not all hosted, indexing of data is provided. Another objective is to provide the spatial and sensor data infrastructure to host TERN data. A third is to improve discovery and access, including via APIs. Long-term visibility is essential. Other objectives are to compute access closer to data, increase skills and ensure impact of data and user engagement. The data model is an essential component (collecting, metadata, publishing, interoperability and understanding). There is a big push to use the Semantic Sensor Network Ontology (see schema.org) and for common vocabularies (e.g., relating to platforms, people etc., with these bared on GCMD terms, scheme.org etc.). An example is vegetation height, where focus is progressively on the region, the platform (e.g. a specific site), the instrument (e.g., clinometer), the property (height), the procedure (methods), spatial resolution, temporal frequency and data type (e.g., csv). Useful websites are **linkeddata.tern.org.au** and **ternaustralia.github.io/ontology term-ssn/**. The aim is to stay with standards (ISO, OGC) and to facilitate transfer to other access portals. So, the whole sequence of data collection, storage etc. is documented. Other sites refer to TERN Skills, TERN Vocabs, TERN data Access, ecocloud, and CoESRA VDI.

**Day 2**

**ICOS network for land products validation.**

**Dario Papale, ICOS Ecosystem Thematic Centre, Italy.** ICOS is a network of sites for CO2 and other GHG monitoring. Ecosystem, Atmospheric and Ocean networks have been established, with the ecosystem component measuring carbon dioxide, methane and nitrous dioxide. There is also a Central Analytical laboratory. IOCS is a European Strategy Forum on Research Infrastructures and gives a long-term perspective and support. Operational and entering the 2nd five year program phase. There are currently 40 high quality ecosystem sites and data are transmitted in near real time to the ETC and carbon portal. See www.icos-etc.eu and /documents/instructions for protocols, which are community generated and reviewed. All data are freely available. The data are received by the ICOS Ecosystem Thematic Centre (ETC), where quality checking etc. is performed. Continuous measures of radiation are made at the ICOS stations at 20 second frequency and full metadata is provided. Future work is focusing on optical thickness and canopy temperature. Eddy covariance towers measure fluxes that vary considerably but more information is needed on the surrounding landscape and particularly that near the tower. The area is characterised using a range of measures including species and health status, tree diameter and height (from which biomass is calculated), green area index and soil organic C and N. Measurements are taken every 5-10 years. To determine the temporal variability, 2-5 plots are measured in the target area (2,000 m2) and tree size, health, green area, litterfall, nutrients of the leaves etc. are measured. Green area index is measured using a number of devices including ceptometers and digital hemispherical photographs. Validation is undertaken using litterfall measurements. Below canopy PAR is also used to evaluate estimation of Green Area Index. Phenology measurements are also going to be undertaken using phenocams (to be installed and using the same standard in the US phenocam network). Above ground biomass is determined from diameter, height and species and allometric equations. TLS is being evaluated and 6 stations have been scanned from which biomass and other metrics are being extracted. ICOS needs data to be requested with particular specification in order to meet the needs of the community. Data are distributed by the carbon portal, with a permanent identifier (PID) and under the Creative Common license. New products can also be requested if justified. ICOS is a stable, long term and sustained infrastructure and high level of interest in establishing links with the remote sensing community; open to discuss new products and adaption of protocols. New measurements can be provided but standardization is needed. Whilst forests were presented, protocols etc. are relevant for grasslands, croplands and mires. Contact darpap@unitus.it or bert.gielen@uantwerpen.be.

**Space missions to measure forests**

**Klaus Scipal (ESA).** The space agencies will deliver measures of forest height, biomass and biomass change. Noted that most of the measurements are indirect. The remote sensing challenge is to develop algorithms that are trained/calibrated with reference data of known quality. Product validation is also essential. Accurate reference data are needed and ground-based infrastructure is as important as the spaceborne component.

Mentioned that forests and hence biomass are constantly changing (see Brienen et al., 2015; Nature). This limits the use of old datasets. However, collecting data that is accurate enough is challenging (e.g., DBH not well defined). Botanical knowledge is also essential to determine biomass and this is particularly important in the tropics. There are a number of inventory databases including RAINFOR (500 biomass and dynamics plots), AfriTRON (> 250 plots), CTFS-ForestGEO (about 61 large dynamic plots including 30 in the tropics) and TMFO (c 490 biomass plots). The data are in different formats though although there is some consistency. Many datasets are also not available and often are acquired without Earth observation in mind. The networks have a long history and experience in building networks of cooperating partners.

The Forest Observation System is a cyberinfrastructure to collect and disseminate ground data and is tailored to needs of the EO community. FOS is not competing with existing initiatives, collects but does not distribute tree level data (only aggregated), and focuses on high quality datasets. The data providers can give access to tree level data on a case by case basis.

FOS started in 2016 as a pilot and is now in an implementation phase, with the development of a webportal, including TMFO and TERN databases, identify and establish collaboration opportunities with research teams and networks collecting high quality data, including LIDAR-based AGB estimates and identifying gaps and encourage investments in field-based observations. The database is available at https/www.forest-obervation-system.net/. French Guiana, Panama and Gabon are well covered with several hundred plots. Tree level data are collected and a biomass R-package is available to provide estimation of biomass (Rejou-Mechain et al., 2017). The code can be accessed at https"//github.com/AMAP-dev/BIOMASS. When select a plot, information is provided with details of the plot itself (i.e., location of subplots and associated information on biomass etc.). LIDAR-derived biomass maps are also available. FOS currently has 275 master plots divided into 1645 subplots at 0.25 ha. Historic data only are available and the next step is to integrate LIDAR data and including new plots and networks. Two papers are published including Chave et al. (2019). Ground data are essential for biomass remote sensing and Schepaschenko et al. (2019).Scientific data (no reference provided). Need to have matching data at the same time when the missions are operating but need data along local and global gradients and data that are accurate and if possible accompanied by LIDAR surveys. Need data within an area of sufficient size. Noted that FOS is only an infrastructure. Future effort needs to focus on ensuring long term collection of data. Many groups on the ground are not focused on EO but their use is essential.

**ESA BIOMASS Mission and the MAAP**

**Clement Albinet (ESA).** The BIOMASS Mission will observe at P-band (70 cm wavelength approx.) and allows estimation of above ground biomass and also height. The three main products will be forest biomass, forest height and disturbance (area of forest clearing). The resolution of the former two will be 200 m resolution with 1 global map every 7 months but 30 m otherwise P-band full polarimetry will be provided with multi-pass interferometry with a 3 days repeat cycle. The first phase (Year 1) will focus on tomography and the second (Years 2-5) on interferometry). Coverage is not provided for North America and Europe. Three methods will be used to retrieve, namely SAR polarimetry, polarimetric SAR interferometry and SAR tomography. Polarimetry will retrieve the forest biomass based on the intensity of the HV signal. PolinSAR is based on retrieval of the phase centre and elevation. P-band penetrates into the middle of the canopy (i.e., the phase centre) and this will differ at HH, VV and HV. These differences in elevation and using a model, vegetation height will be obtained from which biomass will be retrieved. Tomography involves seven acquisitions to build a 3D view of the volume of the forest using different polarisations (HV and HH), with these indicating ground and vegetation volumes and the distribution of biomass within the forest. There will also be an exploitation platform which allows communication and collaboration. All data will be available on a web interface (including computing resources, all data, design and test bench function, collaborative tools and communication mechanisms). ESA will also work with NASA to work on the Joint Mission Algorithm and Analysis Platform model. Up to date data and collaborative systems will be put in place. In summary, launch is expected in 2022 and will be the first P-band SAR mission in space and has a number of secondary applications (e.g., ice, topography, subsurface geomorphology). Contact Clement.Albinet@esa.int.

**The ISRO NISAR**

**Arundhati Misra-Ray (ISRO).** The NISAR design was derived from that of the DESDynI Mission Concept (from 2011). The NISAR now has the S-band and L-band SAR, with ISRO responsible for the S-band payload, satellite, mission control and the launcher. The system will provide single pol, dual pol, compact pol and quasi-quad pol (S-band; HH/HV and VH/VV) and quad pol (L-band) data. The repeat cycle will be 12 days and access will be free and open. The spatial resolution will range from 2-15 m (S-band) and 2-30 m (L-band).

The key objectives relate to ice sheets and glacier response to climate change, carbon storage dynamics and earthquakes, volcanoes and landslides. There is also application in water, forests, agriculture, soil moisture and urgent responses. The mission lifetime is nominally 3 years. An ISRO Science Plan is also published and outlines a wide range of applications. The different operation modes for the NISAR L-band and S-band were outlined as well as in combination (i.e., the joint mode). The observations will be systematic and an observation plan for the globe and also the Indian region and neighbouring countries are also in place. Different types of products will be generated, including the raw (Level-0B), in radar coordinates (Level-1) and geocoded (Level 2). Higher level products will include large area mosaics, forest cover, vegetation biomass, soil moisture and land inundation, deformation maps, snow cover, depth and density and so on. There will be multiple modes of observations and associated products. A number of airborne missions have been conducted in India and also over some sites in the US. An overview of forest related studies and status was provided, noting that India has a comprehensive protocol for forest inventory and that the Forest Survey of India (FSI) is responsible for the National Forest Inventory. There are around 7000 forested grids and 1000 tree outside forests (TOF) grids across India, with these are inventoried every year. For each of these grids, forest and non-forest areas are delineated. Variations in backscatter with leaf on and leaf off were shown for C-band, with this being used to differentiate and track the seasonal development of deciduous forests. Maps of forest biomass have been generated from both L and C-band for some regions and upto 120 Mg ha$^{-1}$. Forest density was also estimated from ALOS-PALSAR-2 data. The India State of Forest Report provides an overview of the carbon and biomass in India's forests and the role of Earth observations. ISRO's(SAC) contribution to the estimation and generation of AGB maps in several sites in India was also highlighted. It was emphasized that the above work is being carried out with support from FSI(MOU was done for this) for ground data collection and validation. Some of these sites can be considered for the LPV Supersites under the CEOS banner.
Replying to the question regarding the availability of S band data from NISAR, over non-Indian sites, Misra told that the locations, relevant modes of operation, and frequency(number) of data takes etc. have to be provided to SAC/ISRO in order to put it up to mission and planning, in advance.

**The CEOS WGCV LPV Biomass Protocol.**

**Laura Duncanson (University of Maryland)** discussed the current status of the CEOS WGCV LPV protocol for biomass. Mentioned the importance of the GEDI and ICESAT-2. ICESAT-2 is a green photon laser which does not penetrate vegetation as well as GEDI but has more points and covers the regions towards the poles. Work is progressing on the boreal region and this is extended now for the pan-boreal region. GEDI is considered to be a better system for the tropics because of the greater ability to penetrate the vegetation. Using the GEDI and ICESAT-2 is difficult though as although the metrics are the same, they represent different things and are not the same observation. The calculations and observations are different and so care needs to be taken in interpreting these. The spatial resolution is different with GEDI illuminating a 25 m circle whilst ICESAT 2 has a smaller footprint but there are more observations along the track. The combination of all the different datasets will vary but there is potential for quite a bit of confusion in the use. For example, there will be different products and merged products. Used the quote "If data are not turned into useful, actional information in a timely fashion then our field is simply recording history rather than changing it" with this justifying the need for the biomass protocol. There are six chapters so far in the 200 page document.

1. Good practices for biomass estimation in the field.
2. Linking remote sensing observations to field estimates
3. Error propagation
4. Recommendations for user-led validation
5. Utility of protocol for other communities
6. Knowledge gaps.

Common issues were conveyed including transparent handling and reporting of errors and consistent definitions, plot size in relation to the resolution of the observing sensors, geolocation accuracy and so on. Airborne LIDAR is particularly useful as it allows scaling to the size of the resolution of interest. Consideration of error propagation is essential and a user-led product validation has been developed. Requirements are for field plot and lidar data over biomass supersites, more systematically acquired TLS and focus on particular regions, improved allometric models, scalable TLS processing algorithms etc. Major regional gaps are in continental Asia, dryland/woodland ecosystems and time-series in the tropics. For implementation, updated reference datasets and validation tools are needed and reference was made to the MAAP. Transparency tracking through the MAAP etc. is being developed and on the fly validation will be provided. Future planning of missions and field data collection is essential, particularly given the need for supporting future missions. A spatial gap analysis is also being developed. The protocol will be sent out for internal review in the spring and then public review in the summer of 2020. Noted that validation requires reference datasets, funding for plot re-census, and airborne and terrestrial laser scanning. Tools for product inter-comparison and transparency are essential.

**Characterisation and propagation of errors in biomass: from reference measurements to maps**

**Stephen Roxborough and Keryn Paul (CSIRO).** Provided an overview of how to do the error propagation from individual trees through to biomass maps, with this involving allometric models and spatial predictive biomass models.

At the ground level, individual trees are measured and scaled to the plot. Plot size is important and this is recognised. All of the individual measurements have to be scaled up to the plot scale, which is achieved using an allometric model. After that, the reference data are translated to a spatial map of biomass.

The components of uncertainty (preferred as a term to error) are systematic error (or bias; or how far away the estimate is from the true value) and the precision (the spread around the estimated value). In error propagation, precision is important and bias should be taken account a priori (as an adjustment).

Starting with the individual tree, an allometirc model is used to generate the tree level biomass estimate. The data need to be collected to build the model (e.g., tree diameter against tree mass). This diameter may be combined with height or other metrics. Errors are:

a) The actual measurement of the diameter (typically 5 %) and the errors tend to cancel with the more trees measured.
b) The biomass undertaken through destructive harvesting also has errors.
c) The moisture content calculation is one example of further error as moisture content is taken from different but not all trees. So, if underestimate then out for all individuals and so there is a covariance term in the analysis and so terms do not cancel.

Fitting the model also leads to errors, including in the determination of slope and intercept (both linear and non-linear models). Uncertainty of the parameter fitting contributes uncertainty.

The model use is also important. In the inventory itself, there are also errors in the diameter measurement for all of the trees in the plot and then there is the prediction error, where the spread around the line feeds into the uncertainty.

Collectively, these lead to uncertainty. There is also uncertainty associated with the choice of models.

Aggregating to the plot level also leads to error propagation. The general equation for error propagation was presented which is an analytical quantification. However, complex equations/models exist and so the Monte Carlo approach through randomised sampling. This approach is generic, transparent and is preferred by the IPCC.

In the Monte Carlo, a resampled allometric model is created. The biomass of each individual in the plot is predicted. Then the individual biomasses are summed to give the total. Random resampling is undertaken and a new model is generated. Multiple predictions are made with the new resampled model and then there is a prediction error. Once there is a prediction for each individual, the biomass for the plot is estimated and again this is repeated. This leads to multiple predictions and then this leads to the average plot biomass estimate and the variance can be calculated from these.

At this point, there are many plots with an average and variance (e.g., 20 plots at a site). Then, we need to generate a map for areas where there are no samples. For this a method of statistical inference is needed to scale the observations. Simple random sampling can be used as the average biomass can then be calculated as well as the variance (which gives between plot variance). This does not give a map.

This requires spatially contiguous auxiliary data (e.g., lidar, radar or interpolated climate data). A model is then needed to link the spatial data with the reference data and benefits from deep knowledge about the reference and auxiliary data.

There are three uncertainty terms; in the auxiliary data, the spatial predictive model fit and the spatial predictive biomass model predictions. The way to do this depends on the nature of the axillary and reference data.

If the reference data were part of a sampling plan (e.g., random or systematic), then a valid and unbiased estimate of the population. If a planned sample, can use model-assisted inference which uses relationships known from the data. If not planned, then have to use model-based inference and there is no reliance on the field data. In general, though, plot data does have uncertainty (this is inherent) so then can use hybrid inference. Each of these inferences have very fundamentally different equations/calculations.

The hybrid interference is the most likely to be used. Here, we have our uncertainty in the plot level data and a model that relates the auxiliary data to the biomass from which the biomass is estimated. An uncertainty map can also be generated.

In this approach we create a resampling predictive biomass model, predict the biomass of each map location (pixel or map unit) and create a map. This results in multiple maps and then get an average and a variance. This is the correctly aggregated or propagated uncertainty. The mean and variance for any given location can be provided.

The set of equations and assumptions were presented and contact Stephen.Roxburgh@csiro.au for information.

**New technologies (TLS/UAV) for biomass validation: status, outlook and recommendations.**
***Kim Calders (Ghent University).*** TLS is more established than UAV and it is recognised by the IPCC. LIDAR is directly related to the structure and allometric models can be retrieved from this. An overview of TLS was provided (see reference slides). Time of flight and phase based methods were outlined, with the latter providing cleaner data. A lidar alternative is the Structure from Motion, which allows 3D point clouds to be generated. The tradeoff is between the level of detail and the area of coverage, with drones allowing hectares to be covered. TLS prices range but for biomass need TOF, low noise and high range and looking at 150 K AU but best to go higher to avoid work load costs. The process of collecting and analysing the TLS data was outlined. This involves translation of points to volume and other metrics. A 1

ha site in the tropics takes about 6 or 7 days and the algorithms for volume determination are already existing and well developed.

Once individual trees have been extracted, modelling uncertainty is undertaken in an iterative way. A protocol for collection has been established and needs to ensure that you minimize occlusion and have a uniform point density. |A grid system is best. A 10 m grid was considered to be useful for tropical forests but 20 m was acceptable for more open temperate forests. Comparisons between actual harvested trees and the scans have been undertaken. In Victoria, the correspondence was far greater with the TLS compared to allometrics. Using the allometric equations, a systematic underestimation was observed particularly at the upper end. Smaller trees were also found to have a higher relative error because leaves occlude the signal. In the tropics (Indonesia and Peru), an underestimation was observed when using allometrics to the TLS was better. An advantage of TLS is that there is no need for DB measrements. However, TLS provides volume but this then has to be converted to biomass through use of wood densities. Leaves cause difficulty and comparison with leaf on and leaf off showed that the leaf on provided less reliable estimates (overestimation by 26%. Leaf removal algorithms have also been developed.

LIDAR drones were also tested, with these including fixed wings and multi-rotor platforms. Legal flying issues are important to consider. Comparisons were made between different systems and these were significant, with greater detection obtained using the higher point density systems. Volume information is more easily retrieved in open forests. From SfM, information on the upper canopy only is obtained.

In summary, TLS is optimal but UAV gives the coverage. Efforts are being made to ensure the TLS data are made available through a metadata platform rather than providing the actual data. Temporal mapping of forests with $CO_2$ enrichment gives a good idea of how forests might be changing. There is a need to use TL as local calibration data to refit current allometric biomass equations, to improve wood density and also the plug and play approach for algorithm development would be good. A quality control framework is also needed but placing hard quality criteria requires careful thought. Of note is that sonic tomography can be used to indicate hollow trees but this is still being explored.

**CCI Biomass**

***Richard Lucas (Aberystwyth University).*** Provided an overview of the BIOMASS CCI project, which has generated global AGB for 2017 using ALOS-2 PALSAR-2 (including ScanSAR) and Sentinel-2 data (dense time-series). Further maps will be produced for 2010 and 2018 and potentially back to the mid 1990s. The future integration of ICESAT-2 and GEDI data was also explained. An overview of the validation datasets was provided and areas of under-estimation and over-estimation were highlighted. Example comparisons with existing land cover maps were also provided and future options for gathering tree level and other structural data were also presented. Suggestions were made to translate the CEOS protocol into a mobile application and also to provide formal training.

**SUPERSITE REVIEWS**

**Litchfield National Park**

***Shaun Levick (CSIRO)***. Provided examples from Litchfield NP of TLS and ALS. Existing allometrics (Wiliams et al., 2015) showed variation in internal allometrics and will AGB. So, there is a move to new allometries. A history of the TLS samples was provided, with data collected from 2013 to 2019, with several associated with towers and vehicle mounted track scans have also been undertaken. Time-series of scans were also compared, showing losses and gains and overhead and side views were provided. Allows quantitative measurement of growth and dieback. This provides a dynamic view of vegetation. Examples of natural growth and dieback but also fire were presented.

By building a rich time series, can look at dynamics and compare against spaceborne missions. Future directions are lidar-based biomass allometrics, establishing repeat survey precision, error propagation from tree to region, partitioning of spatial and temporal uncertainty and biodiversity relationships.

***Lindsay Huntley (CDU).*** Provided an overview of the savannas of northern Australia, stressing the dynamic nature of the environment. The North Australian Tropical Transect (NATT) was also developed. Biomass measurements are in 1 ha plots along the transect (Adelaide River, Howard Springs, Daly River, Dry River and Sturt Plains). The Ti Tree site is also located in the Arid Zone (north of Alice Springs). The sites cover the major rainfall gradient.

The Savanna Supersite has a flux tower and is within Litchfield NP. A number of flora and fauna monitoring sites have been put in place from the mid 1990s onwards. It is a high rainfall ("1960 mm) with regular fires (over 15 burns between 2000 and 2018). Low intensity fires occur early in the dry season. The area represents the landscape of about 60.000 $km^2$. The tower has been operational since 2015. There are 2 x 1 ha vegetation plots, with floristics, biomass, allometry and ALI. LIDAR data have also been acquired through TERN AusCover. In 2019, a very intense fire went over the whole area including the supersite.

**Alice Mulga Supersite**
***James Cleverly (UTS).*** A TERN supersite but also as an OzFlux site. Noted that 70 % of the land is semi-arid (Eamus et al., 2006). Two thirds of NPP from grasses and crops (Haverd et al., 2013). The site focuses on fluxes, ecosystem ecology (including biomass and LAI) and remote sensing calibration and validation. The Ti Tree site is comprised of Acacia woodlands (Mulga), with red gum riparian and hummock grassland (spinifex) savanna. The research infrastructure is outlined in Villeneuve et al. (2015) Journal of Arid Environments. As well as flux towers, there are phenocams, vegetation monitoring plots, airborne LIDAR (not processed) and UAV thermal imagery. Conveyed that publication is essential to get interest in a site. Ti Tree has a hydrologically significant catchment with aquifers and well characterised groundwater surveys. An overview of the Woodforde River was provided and is outlined in Villeneuve et al. ,(2015). Hummock grasslands and Mulga separately cover between 20-25 % of the continental land area, with sharp ecotones in between as they do not overlap. The NCRIS Atlas of Living Australia provides information on the vegetation communities occurring (see Nolan et al., in review). Access to groundwater is important in controlling ecosystem health and distribution (including phenology and productivity).

In 2011, there was a global land C sink anomaly, whereby alot of carbon was taken up by vegetation because of El Nino. The majority was in Australia because of extra variability built in by the Indian Ocean

Dipole and SAM. This results in large amounts of rain. Rammig and Machecha (2015) shows a change in the biomass and productivity of vegetation. Tarin et al. (2020) show the change in the carbon dynamics of the Hummock/Corymbia savanna. In dry years, there is a very strong carbon source from the hummock grasslands. The biomass is approximately 37.5 Mg ha$^{-1}$ but this is based on a Mexican multi-stemmed tree equation. A relationship between basal area and above ground biomass was also reported in Navar et al. (2013). The stem density is high (in the 1000s) but the size of trees is small. The phenological variation is with rainfall and in some years, no or limited greeting is observed. Drone imagery has been acquired (including in the thermal).

**Robson Creek/Daintree Rainforest/Cow Bay**

***Mirko Karan (TERN).*** These sites cover lowland rainforest (Cape Tribulation and Cow Bay) and upland rainforest (Robson Creek). Wet tropics biomass is about 0.26 $ of the Australian land mass. The flux tower has been in place since 2013 in Robson's Creek. The AGB is 420 Mg ha$^{-1}$ and about 270 species occur. The canopy height is about 30 m. UAV campaigns have been conducted as well as TLS The Forest GEO wanted DBH down to 1 cm and so there is a search for funds for a recensus of a 25 ha plot. Cape Tribulation has a canopy crane with associated infrastructure, with a 1 ha crane plo and other control plots. The canopy height is about 25 m. Litterfall, hydrology, soil pits, dendrometer bands and sap flow sensors are in place. There is also infrastructure for research and training. Cow Bay is 15 km from Cape Tribulation and there is a 1 ha plot established in 2013, which was re-censused in 2018. The minimum DBH size was 10 cm. There is also an EC Flux tower. The project is co-funded until 2027 by the Daintree Discovery Centre. Consists of pristine lowland rainforests and mesophyll vine forest. For more information, go to tern.org.au.

**Kim Calders (University of Ghent).** In 2018, TLS data were collected alongside variable density UAV-LS data (Wageningen University and UGENT). Drone data `(VUX LIDAR) data were also flown. All sites were scanned at high density (~1000-50000 points per m$^2$) and all sites also had low res. All data are freely available and will be on the TERN site.

**Day 3. Collaborative opportunities**

Copernicus Global Land Service

(see land.copernicus.eu/global/dataaccessLP/) - products of interest are surface albedo, LAI, soil moisture etc. and there is a need for ground-truth information and particularly automated systems.

For Australia, TERN is the main coordinating body for terrestrial monitoring sites and can contribute to GBOV. Some funding from GBOV is available for instrumentation and field campaigns but this is limited so ongoing support would need to be sought.

DHP and DC data are collected regularly at the TERN sites and most are upward looking. These are acquired in a sample design throughout the site. DHP on 20 x 20 m grids are generally taken. Protocols are also established (e.g., LAI). Downward facing imagery is important to capture the characteristics of the understorey, which rapidly changes in savannas. Phenocams are typically oblique. Advice on the distribution and use of different images would be useful and protocols need to be reviewed (e.g., ICOS) and to make sure sufficient data are collected and are of good quality. Need to consider the heights of the cameras. Sampling schemes also need to be reviewed. Noted that LAI is variable depending on the environment and specific approaches might be needed; there is also differing interest in recording some environmental variables (EVs). Collecting data that can be analysed later on is essential. Minimum requirements for satellite cal/val also need to be determined. A workshop was suggested but annual workshops are held with TERN and so invites to these would be beneficial. A review of methods and the success of retrieval as well as definitions is needed. Also, a review of how to use sensors in combination (e.g., DHP, TLS and FPAR sensors) and intercomparisons are needed. Differentiated between high level (expensive TLS) that are used for biomass but then there are temporal sensors that are less complex and are designed to track changes over time. These sensors can give a vertical profile of plant area index. They also run off small solar panels. Refer to the LEAF (contact darius.culvenor@sensingsystems.com.au. Also, information on phenology can be found at https://www.biogeosciences.net/13/5085/2016/. Mobile litter traps are also useful to support quantification of leaf cover over time. Training is recommended to ensure standardization of the approach and a yearly workshop is undertaken by TERN. Protocols for upscaling also need to be reviewed/collated. Requirements need to be provided. A recommendation was to consider instructional videos, perhaps linked to mobile apps (e.g., for ipads) to standardize processes.

**POLICY NEEDS AND DRIVERS**
**Introduction and objectives for the session**
**Stephen WARD**
CSIRO and GA are joint Chair of the CEOS SIT. The three themes are:

- Analysis Read Data
- Carbon and Biomass
- SDGs

Carbon and biomass is to support the CEOS GHG Roadmap process, with the aim to produce products for the global stocktake, encourage stronger and more systematic CEOS engagement within convention frameworks, reflecting in large investment in biomass missions and accelerate relevance of these new data and promote update of biomass datasets beyond the science community.

- Ambitions. An optimally efficient and effective partnership between space data providers and the main UN and national stakeholders,
- CEOS exploring more integrated and pro-active relationships with major stakeholders in conventions and national inventories, to accelerate the policy impacts and application of our data.
- Shine a light on the technical work underway in the COES and agencies and advocate for support from principals to realise full potential.

The SIT-35 is in Hobart in 3 weeks and making a business case for agency support for implementation of the CEOS Biomass Protocol; where we need agencies to invest and what they get in return.

- Progress thinking on a CEOS AFOLU Roadmap
    - Analogous to GHG Roadmap model
- Drafting started by ESA and CEOS GFOI.
- Vehicle for progress and monitoring within CEOS
- Mile-stone focused (global stocktakes)

Option to develop a land carbon and ocean carbon program, with focus on policy milestones and long term improvement.

Generation inspiration in support of the SIT Carbon and Biomass Strategy.

**Policy needs and drivers**

***Jo Nightingale (NPL, UK) and Martin Herold (Wageningen University).*** Refer to Herold et al. (2019) for information. The achievement of international goals and national commitments requires credible, accurate, reliable and continual monitoring of stocks and changes in forest biomass and carbon.

Gaps remain in the research domain and policy making and reporting requirements. International coordination bodies are integral in addressing these issues.

Forests are strong in the Paris agreement (Article 5) and the land use section has potential for large negative emissions. Forest and soils are the only proven capture and storage at scale but there are nature based solutions.

Key issues including need for regular reporting and stock/taking by countries and globally. Need to stimulate and implement mitigation activities and enhance transparency framework but there are not standardized frameworks to implement the Paris agreement and stock taking.

Private sector initiatives include the New York Declaration on forests (2014), the Amsterdam Declaration (2015), commodity roundtables, European biofuel directive and new evolving market approaches such as ICAO/Corsia sechen efr international aviation. All monitoring requires accountability, transparency, enforcement and interpretation and the supportive data.

Key issues and gaps related to availability of data, but increasing EO with open data policy. Appropriate fit for purpose use of available data. There is an insufficient level of detail in existing freely available datasets relation to resolution and coverage and definitions of forest and biomass used to provide maps versus the ones used in national GHG inventories.

Current biomass maps are static but there is a requirement for ongoing change, there is conflicting information and definition in the complementary use of field and space data and uncertainty characterisation is missing or not well suited. There is also a lack of capacity of key stakeholders. Most countries want to do their own reporting but do not have capacity. Gaps between theoretical opportunities and policy and management.

GCOS Implementation Plan
International frameworks with five actions, including encouraging interagency collaboration and improved access. The requirements from the ECVs have also been reviewed and can be found at https://gcos.wmo.int/en/ecv-review-site

Policy needs include national and global level reporting, national biennial update reports and stocktake summaries. Scaled national produce are available. There is a need to consider differentiated observation needs along the policy cycle reporting including land change trends, GH impacts, ECVS, IPCC science assessment report, policy options and activities including drivers and hotspot emissions and mitigation and then implementation including near real time alerting and interactive systems There is also a need to evaluate the performance of these.

REDD+ has performance based systems, in the context of, for example, the Green Climate Fund.

In the 2019 refinement of the IPCC Good Practice Guidelines, the first update of the AFOLU guidance since 2006 has been conducted and approved by the IPCC plenary in May 2019. There is an increasing role of Earth observations, Tire 1 updates are needed (in particular for forest biomass and regrowth) and guidance of the use of biomass density maps.

Potential use of biomass density maps in the framework of GHG inventories including assessing C stock and emission factors, increase data density in under sampled areas, integration with activity data to produce wall to wall maps estimation and derived estimation of biomass change and verification processes. Eventually need to get to a process where using Earth observation data.

National calibration is required with links to NFII efforts and need to consider uncertainties and perhaps update in the GPG uncertainty changes

There is a need for joint initiatives and data exchange between biomass expert mapping community and contribute to and develop policy and mechanisms for data sharing. There is also a need to develop particular country examples and encourage ownership and to increase capabilities? for continuous improvement and sustainability, including tools and concepts to ensure continuity.

In summary many policy needs versus forest monitoring opportunities. There is a need to connect policy requirements and research capacity in terms of definitions, capacity development and standardization of methods and guidance for global and national data streams and to support agencies/organizations such as CEOS.

**EO and Climate Policy Process**
**Osamu Ochiai (JAXA)**

The 2015 Paris agreement came into force on 4th No 2016. Participants have agreed to commitment to a national determined contribution to hold global warming well below 2 degrees. There are a number of related articles to EO, 3, 4 etc.

International joint efforts include the SBSTA which recognised progress made by the satellite community in the development of the essential climate variable inventory. These were noted and there was considerable support in the negotiations from Japan and EU delegations.

The interface between the policy and organisations such as GEO has been advanced, including representation as an expert organization, space-based ECV contributions through GCOS, space agency statements at COP and SBSTA and representation to Earth information Day at COP. In 2019, CEOS began to coordinate the use of multiple satellite missions to determine above ground biomass which can support forest and carbon emission reporting including the global stocktake.

JAXA and other space agencies are engaging with the IPCC in many ways through various engagement activities but also supporting the use and deployment of satellites. CEOS plays a role in quality control and the accuracy of GHG data. An MOE/NIES Methodology Document has also been developed. There is also engagement with international bodies (e.g., IPCC). The IPCC guidelines have been revised to better address the potential role of satellites for GHG inventories. Note the 2019 refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol, 4, Chapter 2, page 2.20.

The history of CEOS in the carbon domain was listed. See The CEOS Carbon Strategy for the policy document (April 2014). 42 actions were identified in the report. Other activities followed including the CEOS Atmospheric Composition Virtual Constellation (AC-VC) white paper was produced. Information on observations, prior information and outputs were also listed in a system approach adopted to deliver atmospheric carbon dioxide and methane inventories.

A roadmap was also generated, with associated timelines, with this listing the Global Stock Takes in 2023 and 2028 through inventories conducted in 2021 and 2026. In this session, the aim was to contribute to the development of a biomass roadmap.

The actions proposed for CEOS include linking the atmospheric GHG measurement and modelling communities and stakeholders in the national inventory and policy communities, exploit capability and complete an operational space based architecture.

Biomass is increasingly important and GFOI request CEOS improvements to biomass mapping, biomass links to GHG roadmap and global stocktakes etc.

Many current and upcoming missions will provide biomass information and there is increasingly engagement between the different space agencies. There is also a need to look at validation protocols and cross calibration and the data and definition needs.

The feedback included greater funding to support biomass and change estimation from EO but also from the ground. Request that data collected on the ground are relevant and are used. A cost benefit analysis of the variables/methods should be undertaken to optimise efforts. Continental scale campaigns are needed (e.g., a TLS campaign across Europe). Noted that there is a policy schedule and need to link into this in a timely manner.

**National Inventory User Perspective**

**Shanti Reddy (Australian Government).** Outlined the main critical points for national inventory compilers, provided recent examples to illustrate continual improvements and discussed conceptual differences between top down and bottom up approaches for land sector accounting.

National annual reporting cycle. National systems must report annually by 15th April. Guidelines are very generic but are quite focused with room for innovation. Considerable effort is involved and hence there is often not the opportunity to take on new data etc. There are also differences between IPCCS guidelines and the UNFCCC accounting rules and these are subject to expert reviews annually. The Paris Rulebook is available to guide setting up carbon stock takes etc. All are subject to annual revision and recalculations and there is the need to report five carbon pols and not just the above ground biomass. Furthermore, if a new addition (e.g, GEDI), the rules have to be taken back in time. Common Reporting Format tables are used and are online; there are lots of these and about 1200 tables for the LUCF.

New dataset must be consistent with the existing methods over time. There is also a need to link research missions with operational systems such as Landsat and SAR missions and also need to support domestic emissions reduction policies. A detailed account of activities driving emissions, including management activities and natural disturbances. There is also a need to track progress against the agreed targets and consistent quality and data continuity is very critical. Australia needs to reduce emissions by 5 % below 2000 levels by 2020 and 26-28 `5 below 2005 levels by 2030. There is also a need to support National Determined Contributions (NDCs) updates for 2020 and 2025. Datasets provided also give confidence.

The first example was the update to the FullCAM biomass estimation incorporating the latest research and data. Information on minimally disturbed forests was used to select observational points and these were linked to the TERN biomass library (see Roxburgh et al. (2017) and Paul and Roxburgh (2020). These were used to update FullCAM. This identified the maximum biomass that can be achieved in Australia. This has resulted in significant improvements in the carbon accounting for Australia.

The second example was to undertake field and lidar/optical airborne (including drone) validation of the product. Canopy cover and height information could be used.

The third: Cape Grim data were used to update HFC Leakage Factors and allow improvements in industry practice to be quantified and assessed. The data are not directly taken but look at the losses over time and compare the inventory with the observations.

Fourth:  CSIRO has been measuring and modelling fugitive methane emissions from coal seam gas (e.g,. In the Surat Basin).  Some of the measurements have been used to develop the emission factors for the inventory.

Finally, conceptual differences between the top-down and bottom up approach for the land sector accounting were conveyed. Refer to Grassi et al 2018. These compared the two approaches and highlighted that these appeared to differ.   The main reasons relate to the effects of key processes on the land carbon sink.  Direct and indirect human effects on managed and unmanaged land differ but difficult to define and separate these.  The IPCCS uses the managed land proxy and so if managed in any way, these are identified.  But the areas used for establishing how these effects are being captured also differ. So, the processes of quantifying and accounting are different.

In Australia, LULUCF is decreasing significantly as it is in fugitive emissions and industrial processes and product use.   However, emissions are increasing from transport, industrial processes and product use and stationary energy (excluding electricity.).

**CEOS AFOLU Roadmap**

**Osamu Ochiai (JAXA).**  Outlined the concept and scope of the AFOLU Roadmap document.  Author contributions discussed and content opened for discussion with both remote sensing and ground data. Timelines were outlined in terms of producing the White Paper in relation to policy timeframes and requirements. Discussion on the validity of global biomass datasets over time and the implications of changing algorithms.   Conclusion was to evaluate the CCI biomass maps using the CEOS protocols as a first case.

**CEOS biomass recommendations for new acquisitions.**

**Laura Duncanson (University of Maryland)**.  Outlined the airborne LIDAR, field plot and TLS specs (see slide for full list).  Five questions were posed.

a) Other sites that can be added
b) Specific information needed to mobilize new data collection following protocol.
c) Support letter content to facilitate/request new collections
d) Generating tangible examples of actions towards protocol adoption to highlight in pitch to CEOS principals.
e) Requests in relation to funding existing plot networks or airborne data over existing plots.

Suggested a slide template which can be filled in, with focus on the group, opportunities, challenges and what is needed to overcome the challenges.

Ask Laura Duncanson for the slide template.  In the opportunities section, can put in ambitions. Contributions needed to produce the pitch slide set.

**Preparing the CEOS funding pitch**

***Klaus Scipal (ESA).*** All the missions need biomass data at the ground level. Reference measurements follow a well defined and traceable protocol and can be employed as a standard reference system. They are important for calibration, validation and enabling cross calibration between different missions.

The total estimated cost for the relevant ground data measured twice during a 5 year mission life is around 20 M Euro. The best approach is to work with existing networks and so this should be a priority. Also, EO needs to co-fund existing networks.

Recommendations to CEOS were:

- CEOS endorse the list of candidate supersites; based on practical consideration, already have airborne lidar capacity and established permanent plot.
- CEOS to endorse the supersite protocol and only sites that follow this get the label. An internal procedure should be undertaken to obtain the award (helps funding bids also).
- CEOS to encourage national space agencies to support the supersites. Each agency could contribute funding or adopt a supersite and should be encouraged to collaborate with established networks and their local collaborators.
- CEOS should enforce an open and free data policy for the supersites (needs to be a condition).

Questions posed were:

- How to ensure plots are supported in less developed countries.
- Can the supersite table be linked with potential funding agencies.
- How do national plans fit in with CEOS and supersites
- Is there benefit in extending the scope to support other missions (e.g., hyperspectral).
- Can there be a list of contacts with the National Space Agencies that would have authority.
- Can we collect support for developing supersites.

Suggested **formulating a strategic plan for the supersites (biomass reference sites)**, with this considering gaps, number of plots, benefits for space agencies etc. (e.g., as a glossy brochure that references the slides).

**Summary actions**

**Preparing inputs for SIT-35**

- Various group reps to fill in slide template on opportunities & challenges for protocol implementation (TERN (Mirko), JAXA (Osamu), ISRO (Misra-Ray), eLTER, ESA (Klaus), NASA (Laura), Cindy to circulate template
- All LPV reps should brief SIT representatives on biomass protocol before SIT meeting
- Draft SIT slide deck (Laura)
- Development of strategic plan (Richard)

**Protocol Implementation Actions**

- Biomass requirement summary (2-pager) to draft as part of protocol & share with TERN for comment (Laura, John & Mat Disney)
- TERN to review reference site list
- Anybody to add other biomass reference sites
- Template for support letters from TERN to biomass LPV group
- Add ISRO rep (Raj Kumar?) & potentially TERN rep to multi-mission group
- Add 4-5 ISRO sites to supersite (biomass reference site) list (Laura, Nicolas L.)
- Review of application to shrublands (Nancy Glenn)
- Replace biomass 'supersite' with biomass reference site in protocol and elsewhere
- Check eLTER sites that already meet protocol standards (Michael, with John & Laura)

**Preparing inputs to the CEOS AFOLU Roadmap**

- Multi-mission group to look to validate the ESA CCI Biomass map versions using the CEOS Biomass Protocol as an initial product for GST1 (Joint). Create a google doc to carry text (with outline headings). Paragraph for each of GST1 and 2?

**Recommendations for new acquisitions**

CEOS Biomass Recommendations for New Acquisitions

Sites with publicly available field plots and airborne lidar, preferably with TLS

Airborne Lidar Specs

- Minimum 4 shots /$m^2$
- Preferably acquired same season as field plots
- Acquired within 2 years of field acquisition
- Repeated every ~5 years or when disturbance detected
- Area min ~3x3 km (but less OK if using drone)
  - Covers plots + local environmental and forest structure gradient

Field Plot Specs:

- Preferably square plots
  - Minimizes edge effects, easier to link to gridded products
- Min plot size of 0.25 ha in tropics (ideally 1 ha with 25 m subplots)
- Stem-mapped where possible
- Smaller than 0.25 ha in temperate and boreal OK provided airborne lidar
- Measure DBH, height, species (follow plot network protocols)

Sampling of Field Plots for local lidar biomass maps

- Covering gradients sampled by airborne lidar (e.g. topography, biomass range, etc.)
- Sufficient number to train a lidar model (10-30 plots)