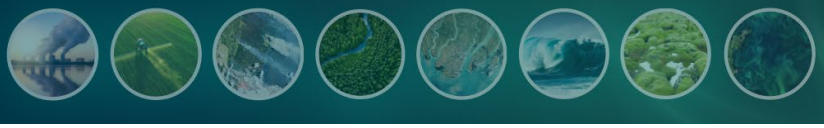
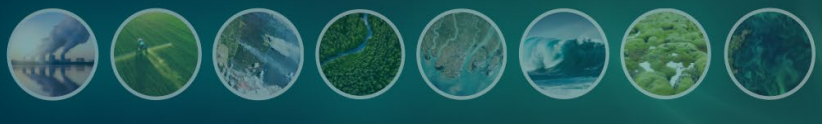


Annex I

Recommendations for Action from the 3rd Carbon from Space Meeting (Land)

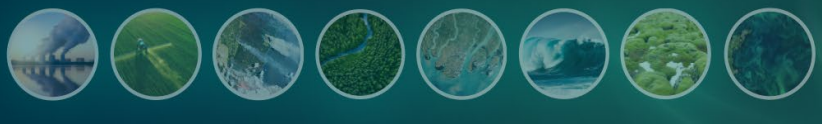
1. *Budgets – Regional*
    a. *Improve partitioning between land and ocean at the regional scale*
    b. *Reduce discrepancies between methods to estimate regional carbon sinks and uncertainties in models at the regional level.*
    c. *Improve understanding of actual drivers of sinks at both global and regional levels;*
    d. *Reduce uncertainty in emissions (both fossil and LUC) and generate annual estimates of LUC to account for important processes (e.g., ENSO-related variability);*
    e. *Improve understanding and characterise the CO_2 versus the effect of climate (and land-use).*
    f. *Explicitly include transport of carbon from land to the oceans*
    g. *Address inconsistency within inversions for both natural CO_2 and CH_4 fluxes needs to be addressed*
    h. *Investigate regional differences between satellite and in-situ observation inversions for natural CO_2 fluxes.*
    i. *Estimates of the global terrestrial carbon sink need to be explicitly derived rather than being based on the residual derived from the difference of the other components*
    j. *For long-term (decadal) carbon balance, improve information on disturbance and regrowth, for an assessment of the site history:*
        i. *Biomass and biomass change (e.g., from BIOMASS, GEDI lidar observations);*
        ii. *High resolution atmospheric CO_2 concentrations*
        iii. *Fluorescence (e.g., GOSAT, FLEX),*
        iv. *Soil moisture*
        v. *Diurnal cycles;*
2. *Fluxes – Regional*
    a. *There remains a lack of consensus between top-down and bottom up estimates for the regional distribution of fluxes despite the inclusion of satellite data to complement for the sparseness of the ground observations*
    b. *There is a need to identify and quantify anthropogenic emissions consistently for policy-making and management, particularly given at least 70% of fossil-fuel CO2 emissions are from urban areas.*
    c. *There is an urgent need to develop advanced systems combining satellite and in-situ observations providing significantly more spatial information to resolve the sub-national and city scale*
3. *Fluxes - Land-atmosphere:*
    a. *Need further development and testing of data assimilation systems with multiple data streams in parallel with forward model developments e.g. TRENDY project and model-independent data-driven machine learning approaches.*
    b. *Need to quantify emissions from fossil fuels with spatial and temporal resolutions higher than those currently available.*
    c. *improve understanding of emissions of CH4 from wetlands and permafrost.*
    d. *understand the effect of the nitrogen cycle on CO2 uptake and fertilisation or limitation processes.*
    e. *include lateral fluxes (mainly transport through rivers) in process models since the anthropogenic disturbance may be as large as 1.0 Pg C yr-1.*



4. *Attribution:*
    a. *Need to improve the spatial resolution in attribution of natural sinks of CO2 from global/continental to regional or local level.*
    b. *Understand the causes of observed increases in the amplitude of the northern hemisphere seasonal cycle in CO2 and the role of terrestrial primary productivity.*
    c. *Improve understanding of changes in the global growth rate of methane, the locations of (changes in) sources, and the causes of these changes.*
    d. *Improve the spatial and temporal distribution of measurements for methane concentration and isotopes to understand and resolve the divergence between top-down and bottom-up estimates.*

5. *Extremes*
    a. *Observational case studies show that the impacts of climate extremes can be identified via remote sensing. However, further studies are needed to understand spatial extent and duration of the impact on the carbon cycle.*
    b. *The interconnected processes through which climate alters the carbon balance are poorly understood and it is important to assess both the impact of extremes on the carbon cycle but also to fully understand the different processes involved.*

6. *Tipping Point/Sensitive Regions*
    a. *Need for long-term, high precision observations in the atmosphere and at the ocean and land surface both in situ and from space.*
    b. *Extend >30-m spatial resolution record and increase frequency from bimonthly to weekly*
    c. *Add regional samples of high (< 1 - 10m) spatial resolution imagery*
    d. *Augment 2-D data with (sub-metre) vegetation vertical structure*
    e. *Quantify photosynthetic rates and vegetation condition (global, sub-km)*
    f. *Improved spatial and temporal coverage and resolution (< 250 m) of coastal margins to constrain carbon/nutrient export from land to ocean*
    g. *Global measurements of CO2 and CH4 at 2-5 km2 resolution, weekly*
    h. *Time resolved observations of CO2 over the diurnal cycle*
    i. *Other trace gas measurements for attribution (CO, NOx, DMS, H2S, OCS)*
    j. *International cooperation incorporating both broad swath, high resolution low earth orbit missions that cover the entire globe and geostationary missions to capture the full diurnal cycle and rapidly varying feature*



7. *Fossil fuel CO2*
    a. *Increase in the density and spatial resolution of atmospheric CO2 measurements from satellites, since fossil fuel emissions are concentrated over small areas.*
    b. *Before 2025, a high-resolution global imaging carbon mission to provide the capacity of quantifying fossil CO2 emissions (≈3 km in size, precision of ≈ 1 ppm and systematic errors < 0.5 ppm.*
    c. *By 2030 a set of carbon missions for the frequent detection, quantification and monitoring of emissions including combined active and passive space-borne sensors and the close coordination internationally of space-based resources to provide continuity and resiliency to losses of data from individual satellites.*
    d. *Close coordination of space-based measurements with each other and with the surface in-situ monitoring network will provide greatest benefit if measurements are calibrated against internationally recognized standards.*
    e. *The development of a Fossil Fuel Data Assimilation System (FFDAS) combining: Emission inventory information, Column integrated satellite CO2 measurements, combustion tracers related to fossil CO2 emissions (e.g., CO) and in-situ atmospheric measurements of CO2 and tracers (e.g., CO, 14C).*
8. *Address key areas:*
    a. *Wetland emissions*
    b. *Carbon in the tropics*
    c. *Carbon dynamics in the boreal permafrost region*
    d. *Carbon exchange of semi-arid regions*
9. *To coordinate between existing structures e.g. NASA CMS, WMO IG3IS, and research efforts of GCP e.g. RECCAP, UCRM and infrastructural networks such as ICOS, NEON and TERN*