**ACTIONS FOR EACH CHAPTER**

**Land**

**Mission-Related:**

**Overall Motivation/Rationale-1:** The *GEO Carbon Strategy* calls for quantification of carbon pools and their changes in response to human intervention and climate to meet the needs of science and policy (section 2.2, p. 10) and, specifically, estimates from space of vegetation aboveground biomass and carbon storage (section 4.6, p. 24). Satellites can provide global information about changes in carbon storage through accurate measurements of forest canopy height and/or estimates of aboveground biomass. Current and planned SAR missions, especially the P-band Biomass mission of ESA, will advance toward this goal. New space-based measurements using lidar, as envisioned to follow the ICESat mission (e.g., the Vegetation Canopy Lidar (VCL) and Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission concepts), and tandem PolInSAR (such as the Tandem-L concept) should have high priority and are recommended to provide complementary information on forest height and structure. Such missions would clearly support the needs of climate treaty frameworks as exemplified by the REDD+ component of the UNFCCC. Airborne lidar measurements to complement SAR missions, e.g., ESA's Biomass mission, are highly desirable in the near- and mid-term to improve accuracy.

**Carbon-Challenge-1:** CEOS acknowledges the challenge to provide accurate measurements of forest canopy height and estimates of aboveground biomass and will influence and coordinate the activities of its Member Agencies toward this goal. CEOS Agencies will consider efforts to provide the needed lidar data and/or inteferometric SAR data (i.e., by considering a new satellite mission and/or by cooperating to assemble existing airborne lidar data and making it available for validation of satellite SAR height and biomass data products).

**Carbon-Action-1:** CEOS Member Agencies with interests in missions and data products for forest canopy height and aboveground biomass will sponsor or co-sponsor one or more workshops (and require a written report) to define the scientific and policy requirements to quantify aboveground carbon storage in vegetation. These meetings should involve the key international science, applications, and remote sensing communities in specifying the technical foundation and scientific requirements for as well as the societal benefits of future missions to quantify aboveground carbon storage in vegetation globally. The workshops should consider these requirements in the context of the added value to be derived from coordinated mission planning and associated data compilation activities both in the future and by exploiting archive data.

**Overall Motivation/Rationale-2:** The IGCO called for in the *GEO Carbon Strategy* requires continuous time series records from satellites of land surface properties (e.g., land cover, land cover change, disturbance, fires, LAI, FAPAR, wetlands, permafrost areas) at mid resolution (Executive Summary, p.7; section 3.2.4, p. 13). To document and analyze changes over time requires continuity of satellite measurements of land surface properties used to estimate carbon pools and fluxes. In order to meet this need, CEOS member agencies must develop and deploy satellites that can provide continuity measurements of land cover, land cover change, disturbance, fires, LAI, FAPAR, wetlands, and permafrost areas at moderate (~250 m - 1 km) and medium (~30 - 100 m) resolution with adequate on-board calibration and sustained calibration/validation operations. Some redundancy to cover contingencies and improve coverage should be part of the overall plan.

**Carbon-Challenge-2:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies so that high-quality, well-calibrated continuity satellite measurements of land cover, land cover change, disturbance, fires, LAI, FAPAR, wetlands, and permafrost are available to estimate carbon pools and fluxes, data gaps are avoided, and satellites flying at the same time, in constellations, and in time series are cross-calibrated and well-validated.

**Carbon-Action-2:** The relevant CEOS VCs and CEOS WG Climate will act to include IGCO priorities for continuity carbon-related observations of the land surface from space in their respective activities to coordinate the VCs and climate-related measurements.

**Product-Related:**

**Overall Motivation/Rationale-3:** The *GEO Carbon Strategy* calls for a continuous supply of mid-resolution Earth observing satellite data (LAI, FAPAR, disturbance, land cover change; Executive Summary, p.7) and notes the extreme value of moderate resolution and high (i.e., referred to as "medium" in the land domain chapter) resolution satellite data for carbon science (section 4.6, p. 23-24). Data products that document the historical records of land surface properties (i.e., forest disturbed area, burned area, timing of burning, LAI, FAPAR, NDVI, land cover, snow cover) at moderate resolution (250 m - 1 km) are needed. Activities that need to be conducted include reprocessing of data to address cloud cover issues in a consistent fashion; merging data from different sensors (e.g., AVHRR, MODIS, (A)ATSR, MERIS, VIIRS, GCOM-C); and, when possible, developing finer spatial resolution products (e.g., 250 m compared to current products at resolutions of 1000 m and greater). The continuity of these moderate resolution records into the future must be assured.

**Carbon-Challenge-3:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the continuity and systematic improvement of moderate-resolution (~250 m - 1 km) satellite time series data products.

**Carbon-Action-3:** CEOS Agencies with historical moderate-resolution (~250 - 1 km) satellite data records will strive to ensure these data are publicly available and used to create the moderate-resolution (~250 - 1 km) records of land properties over the historical satellite record that are useful for carbon science. They will coordinate their efforts with relevant CEOS WGs and VCs.

**Overall Motivation /Rationale-4:**  The *GEO Carbon Strategy* calls for a continuous supply of mid-resolution Earth observing satellite data (LAI, FAPAR, disturbance, land cover change; Executive Summary, p.7) and notes the extreme value of moderate resolution and high (i.e., referred to as "medium" in the land domain chapter) resolution satellite data for carbon science (section 4.6, p. 23-24). Data products that document the historical records of land surface properties (e.g., land cover, land cover change, LAI, FAPAR, forest area disturbed, burned area, areas impacted by insects and storms, and fire severity) at medium resolution (30-100 m) are needed. The collection of global data sets using medium resolution satellite remote sensing systems (vis/IR sensors such as Landsat, SPOT, and IRS and radar sensors such as ERS-1, Radarsat, and JERS-1) has resulted in complete, global-scale data since the late 1990s, with data being available for some regions back to the mid-1970s. Improvement in computer processing speeds and data storage capacity makes processing remote sensing data at medium resolutions at continental and global scale feasible. A number of land remote sensing products listed in Table 2-2 have been developed from medium resolution data, and generation of these products at global scales would provide the ability to reduce uncertainties in terrestrial carbon cycle models. This activity should be extended to the radar archives of ESA, JAXA and CSA.

**Carbon-Challenge-4:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the continuity and systematic improvement of historic medium-resolution (~30 - 100 m) satellite time series data products.

**Carbon-Action-4:** CEOS Agencies with historical medium-resolution (~30 m -100 m) satellite data records will strive to ensure these data are publicly available and used to create the medium-resolution records of land properties over the historical satellite record that are useful for carbon science. They will coordinate their efforts with relevant CEOS WGs and VCs.

**Overall Motivation/Rationale-5:** The IGCO called for in the GEO Carbon Strategy requires continuous time series records of land, ocean, and atmosphere properties (e.g., land cover, land cover change, wetland area, LAI, ocean color and marine ecosystem composition, wetlands, permafrost areas, CO2 and CH4) at mid resolution (Executive Summary, p.7; section 3.2.4, p. 13). It is now possible to develop data fusion and data assimilation algorithms using a combination of remote sensing data (vis/IR, SAR, Lidar) at medium to moderate resolutions to improve the accuracy of land and ocean products. Most of the currently available global remote sensing products are all based on a single instrument approach. To realize the full discrimination potential of the data collected by planned and future remote sensing systems and those currently in orbit, multi-sensor approaches must be developed and tested and a product-based (rather than mission-based) approach must be adopted. To ensure long-term continuity of time series data records, the satellite data provider may need to transition from a research satellite program to an operational satellite program; thus, there must be a continuous interface between the research agencies (e.g., ESA, NASA) and those with operational mandates (e.g., NOAA, Eumetsat) .

**Carbon-Challenge-5:** CEOS acknowledges this challenge and will influence and coordinate the activities of the CEOS Member Agencies toward the continuity and systematic improvement of long time series of multi-sensor, multi-mission data products.

**Carbon-Action-5:** CEOS Agencies with interests in and/or mandates for developing multi-sensor, multi-mission time series data products for the land (and ocean) will strive to ensure consistent, well-calibrated, bias-free satellite time-series carbon products are produced and continued into the future. They will coordinate their efforts in consultation with relevant CEOS WGs and VCs to ensure appropriate merging of data and products from multiple sensors.

**Overall Motivation/Rationale-6:** The IGCO called for in the GEO Carbon Strategy requires improved approaches for developing global land inventories and related data products of 1) the spatial distribution and extent of wetlands and peatlands and of changes in their organic carbon pools and 2) carbon content of reservoirs, lakes, ponds, and rivers (section 3.2.3, p. 12-13; section 5.5, p. 35-36). Satellite observations of inland waters must have appropriate spatial resolution and sensitivities. Lakes and reservoirs cover around 3% of the Earth's land surface, but the majority are small. Use of moderate to coarse resolution ocean-color sensors such as MODIS or MERIS is therefore fairly limited in lake carbon research. On the other hand, many medium to moderate resolution land remote sensing sensors (such as Landsat-7) do not have sufficient sensitivity to estimate lake content of colored dissolved organic matter (CDOM) and monitor long-term trends. At present there are only a few sensors (such as ALI on EO-1) that are suitable for mapping lake CDOM, dissolved organic carbon, and pCO2, but they do not provide full global coverage. Landsat-8 and Sentinel-2 will change the situation, as sensors on both these missions provide data with sufficient spatial and radiometric resolution as well as the global coverage needed for lake research. Space agencies must ensure the continuity of such measurements. Maps of lakes and ponds are needed annually and maps of flooding and inundation are needed seasonally. Estimates of associated carbon-related biophysical properties (e.g., dissolved and particulate carbon, river discharge) and biological productivity are needed as a contribution to terrestrial carbon budgeting. Research agencies must implement projects to develop these essential products at regional and global scales.

**Carbon-Challenge-6:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the continuing deployment of satellites and development of satellite data products for mapping wetlands, wetland types, wetland inundation, rivers, flooding, reservoirs, lakes, and ponds and estimating their associated carbon-related biophysical properties (e.g., dissolved and particulate carbon, river discharge) and biological productivity. CEOS will encourage its Member Agencies to coordinate the launch of satellites that meet requirements in a timely fashion and to avoid gaps. CEOS Agencies will strive to implement projects to develop these essential wetland and inland water data products at regional and global scales and with appropriate spatial and temporal resolutions and sensitivities to the carbon constituents in inland waters.

**Carbon-Action-6:** CEOS Agencies with interests in and/or mandates for developing 1) satellites to observe wetlands and inland waters and 2) wetland and inland water data products will coordinate their efforts in consultation with relevant CEOS WGs and VCs.

**Calibration/Validation-Related:**

**Overall Motivation/Rationale-7:** The *GEO Carbon Strategy* calls for robust carbon tracking and accurate carbon budgets (section 3, p. 11), and these major products require quantitative analysis of changes in Earth system carbon properties over time. This in turn requires well-calibrated satellite sensors and well-validated data products. Development of specific remote sensing products often requires use of surface reference data sets. In some cases, land-based networks have been developed to provide *in situ* data for validation of specific products (e.g., soil moisture, atmospheric CO2), where in others, networks either need expansion or considerable development (such as biomass dynamics). For the ocean, this requires global-scale validation of algorithms for estimating ocean carbon pools from satellite data, in carbon units, in close collaboration with *in situ* observation systems. It is also necessary to provide adequate error characterization of remote sensing variables and carbon products derived from satellite data, ideally on a pixel-by-pixel basis, to ensure their appropriate use in quantifying and modeling carbon dynamics. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community for validation of satellite data products. The CEOS WGCV and its relevant subgroups have conducted and coordinated much-needed calibration and validation work over the years, and this work needs to continue and be expanded. The CEOS VCs are also conducting valuable work in this area. There is a need to strengthen mechanisms within CEOS and at the individual space agency level, in particular investment as part of satellite development, for product validation to establish validation methodologies, protocols and benchmark datasets. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community.

**Carbon-Challenge-7:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the provision of well-calibrated and well-validated satellite data products with adequate error characterization. CEOS will encourage its Member Agencies, to include investment in calibration and validation as part of their satellite development activities. CEOS will promote use of accepted international standards. CEOS Agencies recognize the need to support the WGCV and VCs in these endeavors and to assist in prioritizing activities when resources are limited.

**Carbon-Action-7:** CEOS and CEOS Agencies will encourage national and international agencies to improve and expand upon the availability of the *in situ* observations needed for the calibration and validation of satellite land data products used for carbon science. This will include coordinating with national and international agencies collecting *in situ* data to 1) assess the quality and coverage (spatial and temporal) of validation data and 2) employ design features that entice data sharing and provide safeguards.

**Carbon-Action-8:** The CEOS WGCV's Land Product Validation (LPV) Subgroup will continue its work to validate satellite land data products and expand the number of land variables addressed as priorities are identified and available resources permit, and where no other body takes responsibility (e.g., GOFC-GOLD).

**Motivation/Rationale-8:** The two major products called for in the GEO Carbon Strategy (i.e., a robust and transparent carbon tracking system and accurate carbon budgets; section 3, p. 11) require quantitative analysis of changes in Earth system carbon properties over time. Desirable increases in spatial and temporal coverage can be achieved if data from two different, contemporaneous sensors can be combined seamlessly. To facilitate such data merger or fusion, data products acquired by differing sensors and satellites for each of these properties must be intercomparable, and systematic intercomparison activities must be conducted.

**Carbon-Challenge-8:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the systematic intercomparison of satellite data products of relevance to the carbon cycle. CEOS Agencies will participate, as appropriate, in major intercomparison activities, including model-data, data-data, and multiple data stream intercomparisons. CEOS recognizes that intercomparison activities will require coordination with relevant non-CEOS organizations and activities.

**Carbon-Action-9:** CEOS WGCV and its relevant subgroups, in consultation with the CEOS Carbon Subgroup (recommended in Carbon-Action-38), will organize and coordinate carbon data product intercomparison activities as they are identified as priorities for CEOS action and in coordination with the wider carbon cycle science community.

**Oceans and Inland Waters**

**Mission-Related:**

**Overall Motivation/Rationale-9:** The IGCO called for in the *GEO Carbon Strategy* requires continuous satellite time series records of ocean properties (e.g., ocean carbon state, ocean color and marine ecosystem composition, and ocean physical state) at mid resolution (Executive Summary, p.7; section 3.2.4, p. 13). These biological and physical properties of the ocean are needed to estimate ocean carbon pools and fluxes and document and analyze their changes over time. In order to meet this need, CEOS Member Agencies must develop and deploy satellites that can provide continuity moderate resolution (~0.5 km - 10 km) satellite measurements of ocean color, sea surface temperature, surface winds, salinity, sea state, currents and eddies, sea ice extent and ice edge structure with adequate on-board calibration and sustained calibration and validation operations. Some redundancy to cover contingencies and improve coverage should be part of the overall plan.

**Carbon-Challenge-9:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies so that high-quality, well-calibrated, moderate-resolution continuity measurements of ocean color, sea surface temperature, surface winds, salinity, sea state, currents and eddies, sea ice extent and ice edge structure are available, data gaps are avoided, and satellites flying at the same time, in constellations, and in time series are cross-calibrated and well-validated. CEOS notes that these requirements are commensurate with corresponding GCOS requirements.

**Carbon-Action-10:** The relevant CEOS VCs and CEOS WG Climate will act to include IGCO priorities to extend the time series of moderate-resolution carbon-related observations of the open ocean from space into their respective activities to coordinate the VCs and climate-related measurements.

**Overall Motivation/Rationale-10:** The *GEO Carbon Strategy* points out that carbon fluxes in the coastal ocean are important, yet the coastal ocean is particularly challenging to observe from space (section 4.6, p. 24). The reasons range from the diurnal cycles of the biota to the complex optical properties of coastal waters. In contrast to the open ocean, the high spatio-temporal complexity of coastal regions requires a dedicated, oriented coverage rather than a global coverage. This requires continuity satellite ocean-color measurements with spatial resolution better than 0.5 km and/or repetition rate of less than a day and the capability to observe transitory events (e.g. unusual or transient algal blooms). In addition the challenging optical nature of coastal turbid waters requires more spectral channels in the visible spectrum (e.g., as are available on MERIS) on moderate and coarse resolution sensors than are necessarily required for the open ocean. To meet these needs, CEOS Member Agencies must coordinate the launch of satellites that meet these requirements in a timely fashion to avoid gaps.

**Carbon-Challenge-10:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Member Agencies so that high-quality continuity satellite measurements of coastal waters, with appropriate spatial, temporal and spectral sampling properties, are available for ocean carbon science.

**Carbon-Action-11:** The relevant CEOS VCs and CEOS WG Climate will act to include IGCO priorities for continuity in high-resolution (better than 0.5 km) carbon-related observations of coastal waters from space in their respective activities to coordinate the VCs and climate-related measurements, noting the higher temporal and spatial resolutions and spectral coverage required, compared with open-ocean measurements.

**Overall Motivation/Rationale-11:** The GEO Carbon Strategy points out that carbon fluxes in the coastal ocean are important, yet the coastal ocean is particularly challenging to observe from space. The reasons range from the diurnal cycle of the biota to the complex optical properties of coastal waters. Future geostationary missions dedicated to the observation of the coastal ocean are likely to hold the key to solving this problem (section 4.6, p. 24). New missions and new types of missions are needed to provide higher resolution data than the continuity missions in order to further our understanding of the carbon cycle, especially with respect to phytoplankton functional types, phytoplankton carbon by type, detritus, particulate organic carbon, and aerosols for improved atmospheric corrections. Additionally, it is recognized that there are specific applications in coastal and inland-water bodies that require higher resolution in time, space, and spectral domains to further understanding of carbon cycling. Higher spatial resolution for certain coastal applications (of order 30 m, for applications including floods, tides, river discharge) is needed. Some of these requirements may be met through geostationary satellites. The Geostationary Ocean Color Imager (GOCI) launched by Korea has demonstrated the value of sensors capable of resolving the diurnal signal. Such high temporal resolution is particularly important for dealing with coastal waters because the temporal and spatial scales of relevance in coastal waters are typically smaller than those of the open ocean. Proposed high-spectral resolution polar-orbiting missions for global observations such as NASA's Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) should also be emphasized.

**Carbon-Challenge-11:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the development and deployment of new satellite mission types to provide new information on phytoplankton functional types, phytoplankton carbon by type, detritus, particulate carbon, and aerosols, and 2) provide higher spatial, temporal, and spectral resolution data for coastal and inland waters.

**Carbon-Action-12:** CEOS Member Agencies with interests in and/or mandates for developing and deploying new types of satellite missions to provide 1) new information on phytoplankton functional types, phytoplankton carbon by type, detritus, particulate carbon, and aerosols, and/or 2) higher spatial, temporal, and spectral resolution data for coastal and inland waters will coordinate their efforts in consultation with relevant CEOS WGs and VCs.

**Overall Motivation/Rationale-12:** The *GEO Carbon Strategy* notes that satellite observations of sea surface salinity will benefit efforts to improve estimates of pCO2 (section 4.6, p. 24). Continuity of measurements of sea surface salinity is needed in support this requirement. Improvements in spatial resolution over that of the current SMOS and Aquarius-type sensors will be needed, especially for coastal and inland water applications.

**Carbon-Challenge-12:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the development and deployment satellites to extend the time series of measurements of sea surface salinity and to improve their spatial resolution in the future.

**Carbon-Action-13:** CEOS Member Agencies with interests in and/or mandates for developing and deploying new satellites to measure ocean salinity will coordinate their efforts in consultation with relevant CEOS WGs and VCs.

**Product-Related:**

**Overall Motivation/Rationale-6:** The IGCO called for in the GEO Carbon Strategy requires improved approaches for developing global land inventories and related data products of 1) the spatial distribution and extent of wetlands and peatlands and of changes in their organic carbon pools and 2) carbon content of reservoirs, lakes, ponds, and rivers (section 3.2.3, p. 12-13; section 5.5, p. 35-36). Satellite observations of inland waters must have appropriate spatial resolution and sensitivities. Lakes and reservoirs cover around 3% of the Earth's land surface, but the majority are small. Use of moderate to coarse resolution ocean-color sensors such as MODIS or MERIS is therefore fairly limited in lake carbon research. On the other hand, many medium to moderate resolution land remote sensing sensors (such as Landsat-7) do not have sufficient sensitivity to estimate lake content of colored dissolved organic matter (CDOM) and monitor long-term trends. At present there are only a few sensors (such as ALI on EO-1) that are suitable for mapping lake CDOM, dissolved organic carbon, and pCO2, but they do not provide full global coverage. Landsat-8 and Sentinel-2 will change the situation, as sensors on both these missions provide data with sufficient spatial and radiometric resolution as well as the global coverage needed for lake research. Space agencies must ensure the continuity of such measurements. Maps of lakes and ponds are needed annually and maps of flooding and inundation are needed seasonally. Estimates of associated carbon-related biophysical properties (e.g., dissolved and particulate carbon, river discharge) and biological productivity are needed as a contribution to terrestrial carbon budgeting. Research agencies must implement projects to develop these essential products at regional and global scales.

**Carbon-Challenge-6:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the continuing deployment of satellites and development of satellite data products for mapping wetlands, wetland types, wetland inundation, rivers, flooding, reservoirs, lakes, and ponds and estimating their associated carbon-related biophysical properties (e.g., dissolved and particulate carbon, river discharge) and biological productivity. CEOS will encourage its Member Agencies to coordinate the launch of satellites that meet requirements in a timely fashion and to avoid gaps. CEOS Agencies will strive to implement projects to develop these essential wetland and inland water data products at regional and global scales and with appropriate spatial and temporal resolutions and sensitivities to the carbon constituents in inland waters.

**Carbon-Action-6:** CEOS Agencies with interests in and/or mandates for developing 1) satellites to observe wetlands and inland waters and 2) wetland and inland water data products will coordinate their efforts in consultation with relevant CEOS WGs and VCs.

**Overall Motivation/Rationale-5:** The IGCO called for in the GEO Carbon Strategy requires continuous time series records of land, ocean, and atmosphere properties (e.g., land cover, land cover change, wetland area, LAI, ocean color and marine ecosystem composition, wetlands, permafrost areas, CO2 and CH4) at mid resolution (Executive Summary, p.7; section 3.2.4, p. 13). It is now possible to develop data fusion and data assimilation algorithms using a combination of remote sensing data (vis/IR, SAR, Lidar) at medium to moderate resolutions to improve the accuracy of land and ocean products. Most of the currently available global remote sensing products are all based on a single instrument approach. To realize the full discrimination potential of the data collected by planned and future remote sensing systems and those currently in orbit, multi-sensor approaches must be developed and tested and a product-based (rather than mission-based) approach must be adopted. To ensure long-term continuity of time series data records, the satellite data provider may need to transition from a research satellite program to an operational satellite program; thus, there must be a continuous interface between the research agencies (e.g., ESA, NASA) and those with operational mandates (e.g., NOAA, Eumetsat) .

**Carbon-Challenge-5:** CEOS acknowledges this challenge and will influence and coordinate the activities of the CEOS Member Agencies toward the continuity and systematic improvement of long time series of multi-sensor, multi-mission data products.

**Carbon-Action-5:** CEOS Agencies with interests in and/or mandates for developing multi-sensor, multi-mission time series data products for the (land and) ocean will strive to ensure consistent, well-calibrated, bias-free satellite time-series carbon products are produced and continued into the future. They will coordinate their efforts in consultation with relevant CEOS WGs and VCs to ensure appropriate merging of data and products from multiple sensors.

**Calibration/Validation-Related:**

**Overall Motivation/Rationale-7:** The *GEO Carbon Strategy* calls for robust carbon tracking and accurate carbon budgets (section 3, p. 11), and these major products require quantitative analysis of changes in Earth system carbon properties over time. This in turn requires well-calibrated satellite sensors and well-validated data products. Development of specific remote sensing products often requires use of surface reference data sets. In some cases, land-based networks have been developed to provide *in situ* data for validation of specific products (e.g., soil moisture, atmospheric CO2), where in others, networks either need expansion or considerable development (such as biomass dynamics). For the ocean, this requires global-scale validation of algorithms for estimating ocean carbon pools from satellite data, in carbon units, in close collaboration with *in situ* observation systems. It is also necessary to provide adequate error characterization of remote sensing variables and carbon products derived from satellite data, ideally on a pixel-by-pixel basis, to ensure their appropriate use in quantifying and modeling carbon dynamics. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community for validation of satellite data products. The CEOS WGCV and its relevant subgroups have conducted and coordinated much-needed calibration and validation work over the years, and this work needs to continue and be expanded. The CEOS VCs are also conducting valuable work in this area. There is a need to strengthen mechanisms within CEOS and at the individual space agency level, in particular investment as part of satellite development, for product validation to establish validation methodologies, protocols and benchmark datasets. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community.

**Carbon-Challenge-7:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the provision of well-calibrated and well-validated satellite data products with adequate error characterization. CEOS will encourage its individual space agency members, to include investment in calibration and validation as part of their satellite development activities. CEOS will promote use of accepted international standards. CEOS Agencies recognize the need to support the WGCV and VCs in these endeavors and to assist in prioritizing activities when resources are limited.

**Carbon-Action-14:** The CEOS WGCV, in close consultation with the relevant VCs (that are doing some of this work now), will establish a subgroup dealing with validation and error characterization of ocean carbon-relevant products analogous to the Land Product Validation Subgroup.

**Interactions/Linkages/Communications-Related:**

**Overall Motivation/Rationale-13:** The *GEO Carbon Strategy* calls for robust carbon tracking and accurate carbon budgets (section 3, p. 11). This requires global-scale validation of algorithms for estimating pools and fluxes of carbon from satellite data, in carbon units, in close collaboration with *in situ* observation systems. The Blue Planet Initiative brings together many ocean observation programs with a societal benefit angle, including all the existing ocean observation programs within GEO as well as new ones and fosters synergies among them. Its objectives, as stated on its Web page, are to *1) provide sustained ocean observations and information to underpin the development, and assess the efficacy, of global-change adaptation measures (such as those related to vulnerability of coastal zones, sea-level rise, and ocean acidification), 2) improve the global coverage and data accuracy of coastal and open-ocean observing systems (remote-sensing and in-situ), 3) coordinate and promote the gathering, processing, and analysis of ocean observations, 4) develop a global operational ocean forecasting network, 5) establish a global ocean information system by making observations and information, generated on a routine basis, available through the GEOSS Common Infrastructure, 6) provide advanced training in ocean observations, especially for developing countries, and 6) raise awareness of biodiversity issues in the ocean.* The GEO Task for "Oceans and Society: the Blue Planet" (Task SB-01) thus provides an excellent forum for CEOS and GEO to work together on these issues and CEOS should act to further strengthen and nurture this interaction.

**Carbon-Action-15:** CEOS Agencies will maintain and/or act to strengthen their linkages with the Blue Planet initiative and support of GEO Task SB-01, which brings together the ocean communities engaged in satellite as well as *in situ* observations, to ensure that user requirements are taken into account and products are produced in carbon units.

**Atmosphere**

**Mission-Related**

**Overall Motivation/Rationale-14:** The *GEO Carbon Strategy* emphasizes the importance of satellite observations of CO2 and CH4 in the global atmosphere for monitoring, assessing, and attributing carbon sources and sinks (section 4.5, p. 14-18) and calls for a next generation constellation of greenhouse gas satellite observations (section 5.1.4, p. 26). In addition, there are policy and management needs for this information to support monitoring and verification of CO2 and CH4 emissions for international purposes. A coordinated constellation of passive and active XCO2 and XCH4 remote sensing instruments in Low Earth Orbit (LEO) is needed, with retrieved, single-sounding measurement accuracy of 0.1 to 0.2% for XCO2 and XCH4, a spatial resolution of 1-2 km, and a temporal sampling yielding daily coverage of the entire globe. These missions should be considered in the context of the added value to be derived from coordinated mission planning and associated data compilation activities (spaceborne and in situ/aircraft) both in the future and by exploiting archive data.

**Carbon-Challenge-13:** CEOS acknowledges the challenge to achieve a LEO constellation of satellites to measure atmospheric CO2 and CH4, with appropriate coverage and sensitivity, and will influence and coordinate the activities of its Member Agencies toward this goal.

**Carbon-Action-16:** CEOS Member Agencies with interests in CO2- and CH4-measuring LEO missions will sponsor or co-sponsor one or more workshops (and require a written report) to refine the scientific and policy requirements for quantitative data on atmospheric CO2 and CH4 from low Earth orbit. These meetings should involve the key international science and applications communities in specifying the technical foundation and scientific requirements for as well as the societal benefits of future missions to quantify atmospheric CO2 and CH4 from low earth orbit.

**Carbon-Action-17:** The CEOS Atmospheric Composition VC will coordinate the detailed planning and preparation for a constellation of passive and active remote sensing instruments to measure CO2 and CH4 from low Earth orbit with the higher spatial and temporal resolution and accuracy needed to monitor carbon sources and sinks.

**Overall Motivation/Rationale-15:** The *GEO Carbon Strategy* emphasizes the importance of satellite observations of CO2 and CH4 in the global atmosphere for monitoring, assessing, and attributing carbon sources and sinks (section 4.5, p. 14-18) and calls for a next generation constellation of greenhouse gas satellite observations (section 5.1.4, p. 26). In addition there are policy and management needs for this information to support monitoring and verification of CO2 and CH4 emissions for international purposes. A coordinated constellation of passive XCO2 and XCH4 remote sensing instruments in geostationary orbit is needed to cover all longitudes at a spatial resolution of 1-2 km, with a retrieved, single-sounding measurement accuracy of 0.1 to 0.2% for XCO2 and XCH4 over continents, and a temporal sampling interval of 20 minutes to 1 hour.

**Carbon-Challenge-14:** CEOS acknowledges the challenge to achieve a geostationary constellation of satellites to measure atmospheric CO2 and CH4, with appropriate coverage and sensitivity, and will influence and coordinate the activities of its Member Agencies toward this goal.

**Carbon-Action-18:** CEOS Member Agencies with interests in CO2- and CH4-measuring GEO missions will sponsor or co-sponsor one or more workshops (and require a written report) to refine the scientific and policy requirements for quantitative data on atmospheric CO2 and CH4 from geostationary Earth orbit. These meetings should involve the involve the broad, international science and applications communities in advancing the technical foundation and scientific requirements for as well as the societal benefits of future missions to quantify atmospheric CO2 and CH4 from geostationary orbit.

**Carbon-Action-19:** The CEOS Atmospheric Composition VC will coordinate the detailed planning and preparation for a constellation of passive remote sensing instruments to measure CO2 and CH4 from geostationary orbit covering all longitudes with the spatial and temporal resolution and accuracy needed to monitor carbon sources and sinks.

**Calibration/Validation-Related:**

**Overall Motivation/Rationale-7:** The *GEO Carbon Strategy* calls for robust carbon tracking and accurate carbon budgets (section 3, p. 11), and these major products require quantitative analysis of changes in Earth system carbon properties over time. This in turn requires well-calibrated satellite sensors and well-validated data products. Development of specific remote sensing products often requires use of surface reference data sets. In some cases, land-based networks have been developed to provide *in situ* data for validation of specific products (e.g., soil moisture, atmospheric CO2), where in others, networks either need expansion or considerable development (such as biomass dynamics). For the ocean, this requires global-scale validation of algorithms for estimating ocean carbon pools from satellite data, in carbon units, in close collaboration with *in situ* observation systems. It is also necessary to provide adequate error characterization of remote sensing variables and carbon products derived from satellite data, ideally on a pixel-by-pixel basis, to ensure their appropriate use in quantifying and modeling carbon dynamics. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community for validation of satellite data products. The CEOS WGCV and its relevant subgroups have conducted and coordinated much-needed calibration and validation work over the years, and this work needs to continue and be expanded. The CEOS VCs are also conducting valuable work in this area. There is a need to strengthen mechanisms within CEOS and at the individual space agency level, in particular investment as part of satellite development, for product validation to establish validation methodologies, protocols and benchmark datasets. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community.

**Carbon-Challenge-7:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the provision of well-calibrated and well-validated satellite data products with adequate error characterization. CEOS will encourage its individual space agency members, to include investment in calibration and validation as part of their satellite development activities. CEOS will promote use of accepted international standards. CEOS Agencies recognize the need to support the WGCV and VCs in these endeavors and to assist in prioritizing activities when resources are limited.

**Carbon-Action-20:** The CEOS Atmospheric Composition VC, in cooperation with the CEOS WGCV Atmospheric Composition Subgroup, will provide coordination and support for the cross calibration of all satellite CO2- and CH4-measuring sensors, coordinate their observations, and cross validate their CO2 and CH4 products against accepted international standards, so that they can be integrated into single continuous global climate record.

**Integration**

**Mission-Related:**

**Overall Motivation/Rationale-16:** In order to derive the maximum scientific and societal benefits from future satellite missions focused on carbon-relevant measurements, confirmed missions for continuity and new carbon data products must be launched as planned, and priority new missions should be confirmed as soon as required processes and resources permit. CEOS can identify any opportunities to develop additional items in support of these existing planned missions as joint activities and coordinate the planning of future satellite missions so as to optimize coverage, sampling, and utility of data products, adopting a virtual (or actual) constellation approach, when applicable.

**Carbon-Challenge-15:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the timely confirmation and launch of carbon-related missions and provision of optimized carbon data products. For missions with similar objectives and being developed to fly in the same timeframe, CEOS will encourage coordination of mission attributes so that observations are made in ways that optimize areal coverage, time and space sampling, and/or accuracy. For missions with similar objectives that may follow one another in time, CEOS will encourage coordination of mission and data attributes so that the multiple data streams are compatible and can be integrated to create a consistent time series over a longer time period than any single mission alone could achieve.

**Overall Motivation/Rationale-17:** To ensure that new missions yield the greatest scientific and societal benefits, there is a need for carbon science and policy information priorities to be factored into sensor selection decision-making for future space missions. Thus, it is important that space agencies and their sponsors engage the carbon science community in their mission identification, review, selection, and implementation processes. This will also help to ensure that choices made in response to technical or budget constraints do not compromise mission objectives.

**Carbon-Challenge-16:** CEOS acknowledges this challenge and will encourage its Member Agencies to engage the carbon science and policy communities in their mission identification, review, selection, and implementation processes to the fullest extent possible.

**Product-Related:**

**Overall Motivation/Rationale-6:** The IGCO called for in the GEO Carbon Strategy requires improved approaches for developing global land inventories and related data products of 1) the spatial distribution and extent of wetlands and peatlands and of changes in their organic carbon pools and 2) carbon content of reservoirs, lakes, ponds, and rivers (section 3.2.3, p. 12-13; section 5.5, p. 35-36). Satellite observations of inland waters must have appropriate spatial resolution and sensitivities. Lakes and reservoirs cover around 3% of the Earth's land surface, but the majority are small. Use of moderate to coarse resolution ocean-color sensors such as MODIS or MERIS is therefore fairly limited in lake carbon research. On the other hand, many medium to moderate resolution land remote sensing sensors (such as Landsat-7) do not have sufficient sensitivity to estimate lake content of colored dissolved organic matter (CDOM) and monitor long-term trends. At present there are only a few sensors (such as ALI on EO-1) that are suitable for mapping lake CDOM, dissolved organic carbon, and pCO2, but they do not provide full global coverage. Landsat-8 and Sentinel-2 will change the situation, as sensors on both these missions provide data with sufficient spatial and radiometric resolution as well as the global coverage needed for lake research. Space agencies must ensure the continuity of such measurements. Maps of lakes and ponds are needed annually and maps of flooding and inundation are needed seasonally. Estimates of associated carbon-related biophysical properties (e.g., dissolved and particulate carbon, river discharge) and biological productivity are needed as a contribution to terrestrial carbon budgeting. Research agencies must implement projects to develop these essential products at regional and global scales.

**Carbon-Challenge-6:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the continuing deployment of satellites and development of satellite data products for mapping wetlands, wetland types, wetland inundation, rivers, flooding, reservoirs, lakes, and ponds and estimating their associated carbon-related biophysical properties (e.g., dissolved and particulate carbon, river discharge) and biological productivity. CEOS will encourage its Member Agencies to coordinate the launch of satellites that meet requirements in a timely fashion and to avoid gaps. CEOS Agencies will strive to implement projects to develop these essential wetland and inland water data products at regional and global scales and with appropriate spatial and temporal resolutions and sensitivities to the carbon constituents in inland waters.

**Carbon-Action-6:** CEOS Agencies with interests in and/or mandates for developing 1) satellites to observe wetlands and inland waters and 2) wetland and inland water data products will coordinate their efforts in consultation with relevant CEOS WGs and VCs.

**Overall Motivation/Rationale 18:** There are strong interdependencies among the atmosphere, oceans and inland waters, and land. The fluxes between domains are important, yet it is important to recognize that there is also three-domain coupling since the system under assessment is a cycle and there is strong carbon-climate coupling. Examples of this three-domain coupling include black carbon emissions from fire disturbance and industrial activities and ocean nutrient fertilization from dust aerosols.

**Carbon-Challenge-17:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies so that issues that transcend traditional scientific domains are not overlooked. CEOS will foster communications across CEOS in recognition of the need to support understanding of three-domain coupling of the carbon cycle and strong carbon-climate coupling in the Earth system.

**Carbon-Action-21**: The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will coordinate with other relevant CEOS WGs and VCs to ensure that the carbon observations and data products that transcend traditional scientific domains (e.g. black carbon, nutrient fertilization) are accorded appropriate priority in CEOS activities and future plans and that key satellite products to permit scientific studies of these phenomena are produced and made available.

**Overall Motivation/Rationale-19:** In order to achieve the integrated, global carbon budget analysis called for in the IGCO and meet the needs of the global carbon and climate modeling communities, satellite carbon data products must be consistent and compatible (i.e., temporal and spatial resolution, grids, data formats, units) across the land, oceans and inland waters, and atmosphere domains (e.g., estimates of terrestrial and oceanic primary production should be compatible; ocean products must be compatible, consistent and comparable with the satellite observations of key atmospheric properties (CO2, CH4, NOx, aerosol).

**Carbon-Action-22:** CEOS Agencies engaged in development of carbon products will coordinate to achieve compatibility, comparability and consistency of carbon products across all relevant domains (land, oceans and inland waters, and atmosphere, as appropriate), in consultation with relevant CEOS VCs and WGs.

**Overall Motivation/Rationale-20:** The IGCO called for in the GEO Carbon Strategy requires improved information on natural (section 1, p. 8 and section 3.2.4, p. 13) and anthropogenic ( section 5.4, p. 34-35) emissions of carbon. In addition there are policy and management needs for this information to support monitoring and verification of CO2 and CH4 emissions for international purposes. CEOS member agencies must provide improved information from satellites on the spatial and temporal scale of anthropogenic emissions, in particular fossil fuel emissions from cities, gas flares and power plants and other industrial contributors through cumulation of existing satellite products and initiation of new projects and missions to tackle these issues at a global level. CEOS member agencies must improve the quality of satellite-derived information on emissions from biomass burning, coal mines, rice agriculture, livestock and landfills.

**Carbon-Challenge-18:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies so that improved information on natural and anthropogenic emissions of carbon (CO2, CH4, but also CO and black carbon) is produced and made publicly available.

**Carbon-Action-23:** Individual CEOS Agencies with interests in and/or mandates for providing improved information on natural and anthropogenic emissions of carbon (CO2, CH4, CO and black carbon) will coordinate their efforts in consultation with relevant CEOS WGs and the Atmospheric Composition VC.

**Overall Motivation/Rationale-5:** The IGCO called for in the GEO Carbon Strategy requires continuous time series records of land, ocean, and atmosphere properties (e.g., land cover, land cover change, wetland area, LAI, ocean color and marine ecosystem composition, wetlands, permafrost areas, CO2 and CH4) at mid resolution (Executive Summary, p.7; section 3.2.4, p. 13). It is now possible to develop data fusion and data assimilation algorithms using a combination of remote sensing data (vis/IR, SAR, Lidar) at medium to moderate resolutions to improve the accuracy of land and ocean products. Most of the currently available global remote sensing products are all based on a single instrument approach. To realize the full discrimination potential of the data collected by planned and future remote sensing systems and those currently in orbit, multi-sensor approaches must be developed and tested and a product-based (rather than mission-based) approach must be adopted. To ensure long-term continuity of time series data records, the satellite data provider may need to transition from a research satellite program to an operational satellite program; thus, there must be a continuous interface between the research agencies (e.g., ESA, NASA) and those with operational mandates (e.g., NOAA, Eumetsat) .

**Carbon-Challenge-5:** CEOS acknowledges this challenge and will influence and coordinate the activities of the CEOS Member Agencies toward the continuity and systematic improvement of long time series of multi-sensor, multi-mission data products.

**Carbon-Action-5:** CEOS Agencies with interests in and/or mandates for developing multi-sensor, multi-mission time series data products for the land and ocean will strive to ensure consistent, well-calibrated, bias-free satellite time-series carbon products are produced and continued into the future. They will coordinate their efforts in consultation with relevant CEOS WGs and VCs to ensure appropriate merging of data and products from multiple sensors.

**Carbon-Action-24:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will work to encourage the production and availability of high-quality, consistent long time series data products based on multiple sensors and missions for carbon and climate science and for model-data and data-data intercomparison exercises.

**Carbon-Action-25:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) and relevant VCs will provide periodic technical information to the research and operational space agencies regarding readiness for and issues regarding transitions from research to operations for long-time series carbon observations.

**Overall Motivation/Rationale-21:** In developing an IGCO it is important to ensure consistency of the products derived from satellite observations with, in so far as possible, emphasis on algorithm scale, compatibility, clarity of documentation and, in particular, clarity in the assumptions used to create a given output product. There should also be an endeavor to ensure that output products are appropriately validated using internationally agreed protocols and independently verified *in situ* data. The role of CEOS in this regard extends to ensuring product quality is a priority, independent verification mechanisms exist, there is continuity of data required, products generated are effectively and traceably documented, that inter-comparison between products is undertaken in a collaborative manner and that the appropriate data products are taken and used downstream to both improve scientific understanding of the carbon cycle and establish effective mechanisms in support of policy requirements. CEOS also has an important role to play in promoting policies of free, open, and easy access to data, data products, and documentation for the carbon cycle information needed in support of national and international policies.

**Carbon-Challenge-19:** CEOS acknowledges the challenge to see that products derived from satellite data are consistent and compatible and that requirements for clarity and traceability in products are followed. CEOS will use its influence to encourage CEOS Agencies toward this goal.

**Carbon-Action-26:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38), in consultation with the CEOS WGCV, will develop effective protocols for the generation of products from individual satellites and platforms and encourage their implementation by CEOS Agencies to ensure long-term consistent datasets relevant to carbon cycle community needs. This work shall include accounting for ancillary data dependence (e.g., land cover, aerosol, cloud, DEM, etc.) such that there is consistency across individual products and variables.

**Carbon-Action-27:** CEOS Agencies will make publicly available all information necessary to document the accuracy, clarity, and traceability of the satellite data and data products they produce.

**Carbon-Action-28:** CEOS Agencies will coordinate their efforts to develop compatible (e.g., temporal and spatial resolution, grids, data formats, units) carbon data products from multiple missions, in consultation with relevant CEOS WGs and VCs.

**Carbon-Action-29:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will develop guidelines for the specification of uncertainty for products from signal counts through the various CEOS Processing Levels.

**Carbon-Action-30:** CEOS Agencies will ensure the long-term accessibility of satellite data and data products for carbon cycle science and policy. This must include arrangement for secure archives, documentation, and metadata as well as for provisions for easy discovery and access by the carbon science and policy communities.

**Calibration/Validation-Related:**

**Overall Motivation/Rationale-7:** The *GEO Carbon Strategy* calls for robust carbon tracking and accurate carbon budgets (section 3, p. 11), and these major products require quantitative analysis of changes in Earth system carbon properties over time. This in turn requires well-calibrated satellite sensors and well-validated data products. Development of specific remote sensing products often requires use of surface reference data sets. In some cases, land-based networks have been developed to provide *in situ* data for validation of specific products (e.g., soil moisture, atmospheric CO2), where in others, networks either need expansion or considerable development (such as biomass dynamics). For the ocean, this requires global-scale validation of algorithms for estimating ocean carbon pools from satellite data, in carbon units, in close collaboration with *in situ* observation systems. It is also necessary to provide adequate error characterization of remote sensing variables and carbon products derived from satellite data, ideally on a pixel-by-pixel basis, to ensure their appropriate use in quantifying and modeling carbon dynamics. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community for validation of satellite data products. The CEOS WGCV and its relevant subgroups have conducted and coordinated much-needed calibration and validation work over the years, and this work needs to continue and be expanded. The CEOS VCs are also conducting valuable work in this area. There is a need to strengthen mechanisms within CEOS and at the individual space agency level, in particular investment as part of satellite development, for product validation to establish validation methodologies, protocols and benchmark datasets. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community.

**Carbon-Challenge-7:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the provision of well-calibrated and well-validated satellite data products with adequate error characterization. CEOS will encourage its individual space agency members, to include investment in calibration and validation as part of their satellite development activities. CEOS will promote use of accepted international standards. CEOS Agencies recognize the need to support the WGCV and VCs in these endeavors and to assist in prioritizing activities when resources are limited.

**Carbon-Action-31:** CEOS through its WGCV and relevant VCs will strengthen its mechanisms for product validation by establishing validation methodologies, protocols and benchmark datasets.

**Carbon-Action-32:** For each of the relevant variables in each of the domains CEOS will work with the carbon science community to assess the current provision of validation data in terms of quality (defined by protocols (e.g., WGCV LAI protocol) and or maturity matrices (e.g., WG Climate)) and spatial and temporal coverage. This work should identify potential additional sources and develop a strategy to improve global *in situ* data distributions in relation to satellite validation and model parameterization. It should also exploit existing infrastructures to develop key intensive collection sites.

**Motivation/Rationale-8:** The two major products called for in the GEO Carbon Strategy (i.e., a robust and transparent carbon tracking system and accurate carbon budgets; section 3, p. 11) require quantitative analysis of changes in Earth system carbon properties over time. Desirable increases in spatial and temporal coverage can be achieved if data from two different, contemporaneous sensors can be combined seamlessly. To facilitate such data merger or fusion, data products acquired by differing sensors and satellites for each of these properties must be intercomparable, and systematic intercomparison activities must be conducted.

**Carbon-Challenge-8:** CEOS acknowledges this challenge and will influence and coordinate the activities of CEOS Agencies toward the systematic intercomparison of satellite data products of relevance to the carbon cycle. CEOS Agencies will participate, as appropriate, in major intercomparison activities, including model-data, data-data, and multiple data stream intercomparisons. CEOS recognizes that intercomparison activities will require coordination with relevant non-CEOS organizations and activities.

**Carbon-Action-33:** CEOS will reinforce the mechanisms already in place in CEOS for all domains (WGCV, and VCs, and WG Climate) and clarify their responsibilities to ensure intercomparison activities are well-coordinated and effective.

**Carbon-Action-34:** Individual CEOS Agencies producing the same (or similar) carbon data products will cooperate to ensure that their products are compared to the other relevant products and, if technically feasible, ensure efforts are made so that their products can be used quantitatively with these other products.

**Carbon-Action-9:** CEOS WGCV and its relevant subgroups, in consultation with the CEOS Carbon Subgroup (recommended in Carbon-Action-38), will organize and coordinate carbon data product intercomparison activities as they are identified as priorities for CEOS action and in coordination with the wider carbon cycle science community.

**Motivation/Rationale 22**: In order for the satellite data and data products required for the IGCO to be identified, prioritized, developed, and utilized effectively, CEOS must establish effective linkages with the carbon science, applications, and policy communities. CEOS must work with organizations representing these communities to understand needs and priorities and to ensure satellite data products provided by CEOS Agencies meet needs and are utilized appropriately. CEOS should actively pursue a role within major model-data inter-comparison exercises dedicated to the carbon cycle (e.g., CxMIP, OCMIP, RECCAP) as the point of reference for appropriate satellite products. An effective way to proceed may be through the sponsorship of international workshops on the interface between models (land-oceans and inland waters-atmosphere) of the carbon cycle and satellite data products to reconcile methodological differences and spatial compatibility.

**Carbon-Action-35:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will develop guidelines for appropriate data use of satellite data and data products. This will require improved interactions between the carbon cycle community and the satellite community; comprehensive review of the current use of data products, including current data limitations; and reconciliation of methodological differences and spatial compatibility. Such interactions may include co-sponsorship of joint workshops targeting specific data needs and investment in community product assessments, especially for key intercomparison exercises.

**Interactions/Linkages/Communications-Related:**

**Motivation/Rationale-22**: In order for the satellite data and data products required for the IGCO to be identified, prioritized, developed, and utilized effectively, CEOS must establish effective linkages with the carbon science, applications, and policy communities. CEOS must work with organizations representing these communities to understand needs and priorities and to ensure satellite data products provided by CEOS Agencies meet needs and are utilized appropriately. CEOS should actively pursue a role within major model-data inter-comparison exercises dedicated to the carbon cycle (e.g., CxMIP, OCMIP, RECCAP) as the point of reference for appropriate satellite products. An effective way to proceed may be through the sponsorship of international workshops on the interface between models (land-oceans and inland waters-atmosphere) of the carbon cycle and satellite data products to reconcile methodological differences and spatial compatibility.

**Carbon-Action-36:** CEOS will strengthen linkages with relevant carbon communities and organizations to facilitate the communications and coordination necessary to ensure that the satellite data products provided by CEOS Agencies meet needs and are utilized appropriately.

**Carbon-Action-37:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will serve as a point-of-contact for appropriate satellite products for major model-data intercomparison exercises related to the carbon cycle.

**CEOS Mechanisms- and Future Planning-Related:**

**Overall Motivation/Rationale-23:** In order for CEOS to act effectively on the findings and recommendations of this report, a responsible CEOS entity must be identified. The responsible entity must establish strong working relationships with all relevant VCs and CEOS Working Groups, especially the WG Climate and WGCV.

**Carbon-Action-38:** CEOS will establish a group to be responsible for carbon activities within CEOS and for advancing the findings and recommendations of this report. This group will take responsibility for overseeing, coordinating, and reporting on the actions identified in this report. It is recommended that CEOS establish a Carbon Subgroup within the CEOS WG on Climate as a most efficient way of implementing this action (this recommended group will hereafter be referred to as the “Carbon Subgroup”). The Carbon Subgroup will report to (and through) the WG Climate. It will establish strong working relationships with all relevant VCs and CEOS WGs, especially the WGCV.

**Overall Motivation/Rationale-24:** There is a strong need for CEOS to better understand and further prioritize the needs of the carbon community for space-based measurements in the context of time (2015-2020-2025) and space (i.e., needs for increased resolution) and then to reinforce multi-agency planning and preparation for satellites, as coordinated through the CEOS Carbon Subgroup (recommended in Carbon-Action-38) and relevant VCs to ensure that these priority observations are made in the future. It will be important to identify the priority missing components for emissions/stock assessment that are capable of being addressed with satellite data sources. Also, the *GEO Carbon Strategy* does not provide the level of detail for measurement specifications or observation attributes necessary for a space agency to design a mission or verify if a current or planned sensor can provide adequate data. These specifications, custom for carbon -- and especially when they differ from those for the ECVs -- are urgently needed.

**Carbon-Challenge-20:** CEOS acknowledges this challenge and will engage the carbon science and policy communities to develop a more refined understanding of requirements and priorities for carbon-related measurements from space. CEOS recognizes this will require coordination with GEO, IGBP, Future Earth, and other relevant international organizations.

**Carbon-Action-39:** CEOS and individual CEOS Agencies will sponsor (or co-sponsor) work (e.g., one or more workshops, a written report) to 1) develop more specific measurement requirements for continuing and new carbon observations from space that will fulfill science and policy needs and 2) encourage further prioritization of these measurements.

**Carbon-Action-40:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will lead in the planning for activities to 1) develop more specific measurement requirements for continuing and new carbon observations from space that will fulfill science and policy needs and 2) encourage further prioritization of these measurements. It will work, in consultation with the relevant VCs, to coordinate the incorporation of the refined requirements and priorities into multi-agency planning and preparation for future satellites.

**Way Forward**

**Mission-Related:**

**Overall Motivation/Rationale-16:** In order to derive the maximum scientific and societal benefits from future satellite missions focused on carbon-relevant measurements, confirmed missions for continuity and new carbon data products must be launched as planned, and priority new missions should be confirmed as soon as required processes and resources permit. CEOS can identify any opportunities to develop additional items in support of these existing planned missions as joint activities and coordinate the planning of future satellite missions so as to optimize coverage, sampling, and utility of data products, adopting a virtual (or actual) constellation approach, when applicable.

**Carbon-Challenge-15:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the timely confirmation and launch of carbon-related missions and provision of optimized carbon data products. For missions with similar objectives and being developed to fly in the same timeframe, CEOS will encourage coordination of mission attributes so that observations are made in ways that optimize areal coverage, time and space sampling, and/or accuracy. For missions with similar objectives that may follow one another in time, CEOS will encourage coordination of mission and data attributes so that the multiple data streams are compatible and can be integrated to create a consistent time series over a longer time period than any single mission alone could achieve.

**Calibration/Validation-Related:**

**Overall Motivation/Rationale-7:** The *GEO Carbon Strategy* calls for robust carbon tracking and accurate carbon budgets (section 3, p. 11), and these major products require quantitative analysis of changes in Earth system carbon properties over time. This in turn requires well-calibrated satellite sensors and well-validated data products. Development of specific remote sensing products often requires use of surface reference data sets. In some cases, land-based networks have been developed to provide *in situ* data for validation of specific products (e.g., soil moisture, atmospheric CO2), where in others, networks either need expansion or considerable development (such as biomass dynamics). For the ocean, this requires global-scale validation of algorithms for estimating ocean carbon pools from satellite data, in carbon units, in close collaboration with *in situ* observation systems. It is also necessary to provide adequate error characterization of remote sensing variables and carbon products derived from satellite data, ideally on a pixel-by-pixel basis, to ensure their appropriate use in quantifying and modeling carbon dynamics. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community for validation of satellite data products. The CEOS WGCV and its relevant subgroups have conducted and coordinated much-needed calibration and validation work over the years, and this work needs to continue and be expanded. The CEOS VCs are also conducting valuable work in this area. There is a need to strengthen mechanisms within CEOS and at the individual space agency level, in particular investment as part of satellite development, for product validation to establish validation methodologies, protocols and benchmark datasets. This must be guaranteed on timescales relevant for key science and policy problems and should be closely coordinated with the *in situ* observation community to ensure in situ data are accessible to the satellite community.

**Carbon-Challenge-7:** CEOS acknowledges this challenge and will influence and coordinate the activities of its Member Agencies toward the provision of well-calibrated and well-validated satellite data products with adequate error characterization. CEOS will encourage its individual space agency members, to include investment in calibration and validation as part of their satellite development activities. CEOS will promote use of accepted international standards. CEOS Agencies recognize the need to support the WGCV and VCs in these endeavors and to assist in prioritizing activities when resources are limited.

**CEOS Mechanisms- and Future Planning-Related:**

**Overall Motivation/Rationale-23:** In order for CEOS to act effectively on the findings and recommendations of this report, a responsible CEOS entity must be identified. The responsible entity must establish strong working relationships with all relevant VCs and CEOS Working Groups, especially the WG Climate and WGCV.

**Carbon-Action-38:** CEOS will establish a group to be responsible for carbon activities within CEOS and for advancing the findings and recommendations of this report. This group will take responsibility for overseeing, coordinating, and reporting on the actions identified in this report. It is recommended that CEOS establish a Carbon Subgroup within the CEOS WG on Climate as a most efficient way of implementing this action (this recommended group will hereafter be referred to as the “Carbon Subgroup”). The Carbon Subgroup will report to (and through) the WG Climate. It will establish strong working relationships with all relevant VCs and CEOS WGs, especially the WGCV.

**Overall Motivation and Rationale-25:** In order for CEOS to act effectively on the findings and recommendations of its Strategy for Carbon Observations from Space, regular follow-up and reporting on progress made in implementing will be essential.

**Carbon-Action-41:** The CEOS Carbon Subgroup will report to the CEOS WG Climate. It will track and report upon progress in responding to the actions in the *CEOS Strategy for Carbon Observations from Space* in a manner similar to that for the *CEOS Response to the GCOS Implementation Plan (IP)*, which includes at a minimum annual reporting by the Carbon Subgroup through the WG Climate to the CEOS SIT and Plenary.

**Overall Motivation/Rationale-24:** There is a strong need for CEOS to better understand and further prioritize the needs of the carbon community for space-based measurements in the context of time (2015-2020-2025) and space (i.e., needs for increased resolution) and then to reinforce multi-agency planning and preparation for satellites, as coordinated through the CEOS Carbon Subgroup (recommended in Carbon-Action-38) and relevant VCs to ensure that these priority observations are made in the future. It will be important to identify the priority missing components for emissions/stock assessment that are capable of being addressed with satellite data sources. Also, the *GEO Carbon Strategy* does not provide the level of detail for measurement specifications or observation attributes necessary for a space agency to design a mission or verify if a current or planned sensor can provide adequate data. These specifications, custom for carbon -- and especially when they differ from those for the ECVs -- are urgently needed.

**Carbon-Challenge-20:** CEOS acknowledges this challenge and will engage the carbon science and policy communities to develop a more refined understanding of requirements and priorities for carbon-related measurements from space. CEOS recognizes this will require coordination with GEO, IGBP, Future Earth, and other relevant international organizations.

**Carbon-Action-39:** CEOS and individual CEOS Agencies will sponsor (or co-sponsor) work (e.g., one or more workshops, a written report) to 1) develop more specific measurement requirements for continuing and new carbon observations from space that will fulfill science and policy needs and 2) encourage further prioritization of these measurements.

**Carbon-Action-40:** The CEOS Carbon Subgroup (recommended in Carbon-Action-38) will lead in the planning for activities to 1) develop more specific measurement requirements for continuing and new carbon observations from space that will fulfill science and policy needs and 2) encourage further prioritization of these measurements. It will work, in consultation with the relevant VCs, to coordinate the incorporation of the refined requirements and priorities into multi-agency planning and preparation for future satellites.

**Overall Motivation/Rationale-26:** This report poses contextual Challenges that identify important missions, data products and activities necessary for a useful IGCO. While none of these are within CEOS' and/or CEOS Agencies' capacity to address wholly, it is desirable to maintain attention on these needs, periodically assess progress, and ask if there are things CEOS can do to facilitate further progress.

**Carbon-Action-42:** CEOS will periodically (approximately every 3-5 years) assess progress toward meeting the challenges identified in this report. This may be accomplished through a variety of means, including but not limited to workshops, ad hoc studies, or discussions within or among relevant CEOS WGs and VCs.