Microsoft

AI for Earth Grantee Profile

Chloris Geospatial

Using spaceborne sensors and AI to measure forest biomass

Summary

In the wake of Glasgow COP26, world leaders are aligned in their commitment to reduce atmospheric carbon and keep global warming below the critical 1.5°C threshold. Making good on this promise requires changing the way forests and landscapes are managed. Microsoft Planetary Computer partner Chloris Geospatial has developed a unique technology that goes beyond monitoring forest cover—the traditional monitoring approach—to measure directly the growth and degradation of above-ground biomass over time, providing accurate, global measurements of a crucial component of earth's carbon stock. Chloris' proprietary solution uses satellite data and machine learning to transform how forests and other ecosystems are monitored. At 30-meter resolution, it offers accurate insight into changing carbon stock at the global, national, regional, and even the project level. Chloris' Biomass Map on the Planetary Computer is a 5-kilometer version of the company's proprietary data product, which offers public and private-sector decision makers alike the ability to monitor progress toward environmental commitments; the Biomass Map also showcases a pilot area at 30-meter resolution, the more granular operational scale, to show how investors and asset managers can use this data to assess the impact of particular environmental interventions and plan projects down to the hectare. The Chloris Biomass Map introduces both accountability and strategic insight at a time when the planet needs every carbon dioxide removal (CDR) effort to count.

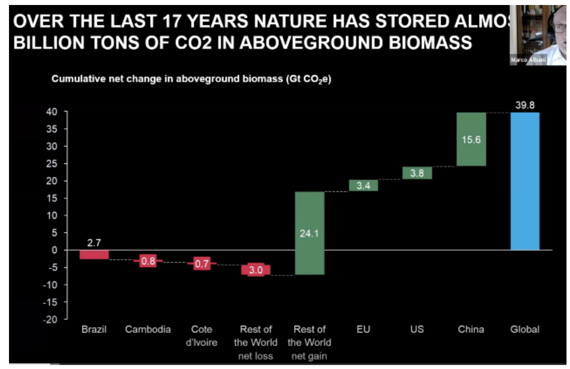
Restoring the carbon balance to fight climate change

Climate change is rapidly accelerating beyond the earth's ability to recover. Carbon dioxide, the principal driver of rising global temperatures, has reached its highest concentration in the atmosphere in 2 million years. The UN's Intergovernmental Panel on Climate Change (IPCC), the internationally accepted authority on climate change, warns that without immediate reduction in atmospheric carbon dioxide, the planet will reach a tipping point beyond which lies widespread, irreversible destruction of the systems that sustain human life. Keeping below this

> "Can nature store carbon at scale and take carbon out of the atmosphere at scale? The answer is a resounding yes." Marco Albani, CEO of Chloris Geospatial

threshold, the IPCC's 2021 report has made clear, will take not only a reduction in carbon emissions, but also the active removal of carbon from the atmosphere.

We have a natural ally in this effort: the forest. According to a 2021 study published in [Nature Climate Change]() by scientists from NASA, WRI, CIFOR, and other organizations, the world's forests remove a net 7.6 billion metric tons of carbon dioxide from the atmosphere each year. The earth's vegetation acts as a natural carbon sink, absorbing carbon dioxide through photosynthesis and transforming it, essentially, into wood. Trees are "the only tech that can deliver at scale to mitigate climate change right now," observes Chloris CEO Marco Albani. "Can nature store a lot of carbon at scale and take a lot of carbon out of the atmosphere at scale? The answer is a big resounding yes."



Measuring environmental impact directly

Forests are critical to reducing carbon dioxide in the atmosphere, and many public and private efforts have focused on planting trees, restoring the forest ecosystem, and shifting forestry and agriculture practices to minimize damage to forests. But how much impact do these efforts really have on the atmosphere? Until now, decision makers have operated more or less in the dark, having to rely only on indirect measures of carbon, such as land cover, or by tracking activities that they have to believe ensure that their nature-based solutions are having the intended impact.

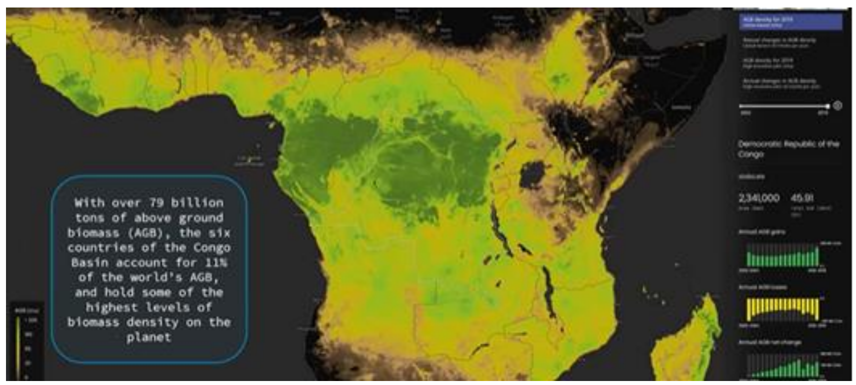
But these tracking methods are not enough to ensure that we are actually moving the needle on global warming. Given the complexity of Earth's interconnected ecosystem, well-intentioned solutions may displace the problem elsewhere; have less impact than expected; or, at worst, do further damage. Without scalable, direct measurement of actual growth or degradation of ecosystems, it is going to be impossible to accurately determine the impact of nature-based solution. Policy makers and asset managers alike need visibility into environmental impact in real time and on a large scale, which inclues the context of the ecosystems they work on, in order to guide effective approaches.

Tracking carbon absorption through forest biomass change

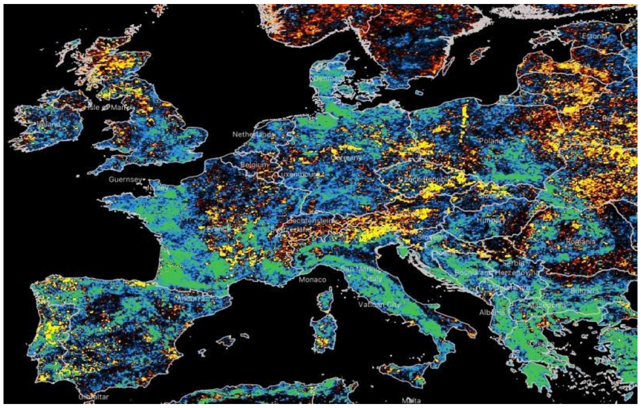
Tracking the impact of environmental policies and projects on carbon reduction is the mission of Microsoft Planetary Computer partner Chloris Geospatial (named after Chloris, Greek goddess of new growth and flowers; "I first scattered new seed across countless nations." (Ovid, *Fasti* 5.193ff)). The amount of carbon in forest vegetation is measurable as a percentage of its dry weight. As such, the change in forest biomass—the mass or density of living matter in a unit area—is a reliable proxy for an increase or reduction in atmospheric carbon. Chloris tracks biomass instead of forest canopy coverage, the traditional focus of forest change tracking, because biomass is a measure of the amount of carbon stored in vegetation. An increase in biomass indicates a corresponding decrease in carbon dioxide in the atmosphere.

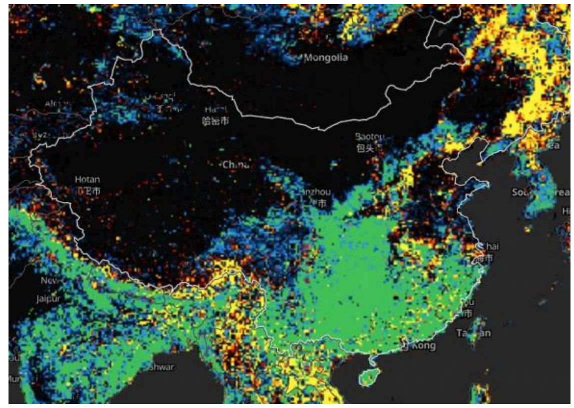
Using spaceborne sensors and machine learning, Chloris' datasets pioneer a new approach to measuring the change in above-ground biomass in a specified place and time. The technology is novel in its accurate and timely accounting of terrestrial biomass at a planetary scale. The datasets Chloris has produced are at once comprehensive and granular. The company offers three different levels of resolution, at 5-kilometer, 500-meter, and 30-meter spatial resolution. The 5-km resolution delivers visibility at global, national, and regional scale; the 30-meter, at a local, project level—even down to the hectare or less. A mid-range of 500 meters is also available for monitoring a broader project area.

The recent release of the Chloris Biomass Map makes the global 5-km data from 2003 to 2019 at annual time steps (with 2020 available in Q1 2022) available free to the public for non-commercial use,.



Hosted on the Microsoft Planetary Computer, this user-friendly interactive map brings the data alive and puts it in the hands of decision makers beyond the scientific community—policy makers, natural asset managers, investors, and the interested public. Users can search by nation or region, using a slider to designate a specific timespan or single year. The map displays insights for some of the most critical fronts in the fight against global warming—the Congo basin (which alone accounts for 11 percent of the world's aboveground biomass), China, and Brazil, for example. Users can identify which countries and regions have seen the largest sequestration of carbon in their biomass stock and which have suffered the greatest loss of forest cabon, and can track loss and gain dynamics across regions. Accessed on the Microsoft Planetary Computer platform, the map may be viewed alongside other terrestrial datasets—biodiversity maps like the Global Biodiversity Information Facility's documentation map of more than 1.6 billion species; on-the-ground plot surveys like the U.S. Forest Service's Forest Inventory and Analysis program; wildfire trackers such as the U.S. Monitoring Trends in Burn Severity; and other biomass maps such as the Harmonized Global Biomass for 2010, which covers both aboveground and belowground biomass carbon density at 300-meter resolution. Users can cross reference these resources and develop insights or hypotheses to explain carbon absorption patterns.





The European Union (left) sequestered over 3.4 Gt CO2e from 2003-2019; China (right)'s large-scale ecological restoration resulted in 15.6 Gt CO2e absorption.

The Chloris Biomass Map includes a pilot of the groundbreaking 30-meter resolution, allowing users to preview the astounding level of detail available commercially. These higher resolution local datasets are optimized for operational use—say, for a natural asset program manager monitoring progress in a specific area or a business running projects to identify areas with the highest carbon stock. With the 30-meter or midrange 500-meter resolution data, users can examine the biophysical track record of a project area. They can answer questions like "How did the carbon stock change in a specific period?" "When did the change happen?" "How did carbon increase or decrease relative to surrounding areas?" The accuracy of the higher-resolution dataset makes it a promising solution for carbon crediting on the carbon markets. It may be used by experts monitoring the risk to forests within supply chains. In environmental finance, the tool can help investors determine where best to infuse capital to support carbon capture. And civic leaders can gain insight into the changing carbon stock of their local jurisdictions. At the national level, governments can monitor progress toward their nationally determined contributions under the Paris Agreement.

Bringing together science and environmental decision-making

As a company, Chloris Geospatial bridges the worlds of scientific research and environmental stewardship—the four cofounders bring a unique blend of skills, with decades of experience in academic science, environmental NGOs, sustainability and business. Chief scientist Alessandro Baccini and CEO Marco Albani met 20 years ago as forestry students and both completed PhDs and postdocs in environmental science with a focus on technological approaches—remote sensing for Baccini and information modeling for Albani. Over the past 20 years, Baccini has pioneered methodologies to measure and monitor biomass from space as a senior scientist at the Woods Hole Research Center and as a member of the NASA Carbon Monitoring System. His scientific breakthroughs, published over two decades in influential journals such as *Science* and *Nature*, are the basis of Chloris' technology. Albani and Giulio Boccaletti, a PhD in climate science from Princeton and a former research scientist at MIT, met at McKinsey & Company where they contributed to found the firm's sustainability practice and where Boccaletti was a partner. Each went on to lead an environmental NGO: Albani as senior director of the World Economic Forum and the inaugural director of Tropical Forest Alliance, which helps remove deforestation from commodity supply chains; and Boccaletti as chief strategy officer and global managing director for water at The Nature Conservancy. Boccaletti brings extensive experience on the role natural capital plays in the economy, broadening the reach of Chloris' technologies beyond carbon. His recent book *Water: A Biography*, a history of how water shapes civilization, was named one of the best books of 2021 by *The Economist*. Mark Friedl, a professor at Boston University alongside Baccini, is the Director of BU's Center for Remote Sensing and a veteran in the use of remote sensing to examine biogeophysical processes. He has extensive experience on NASA and USGS science teams, including NASA's MODIS Land Science Team, the Suomi VIIRS Land Science Team, the Multi-Source Land Imaging Team, the USGS Landsat Science Team among others. His previous venture was TellusLabs, a remote sensing technology company focused on agriculture and acquired by Indigo Ag.

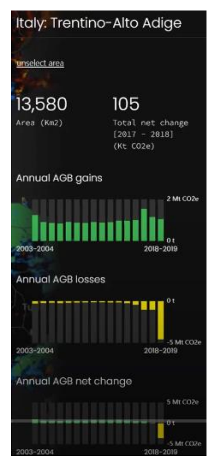
The four founded Chloris Geospatial to get scientific insight into the hands of decision makers faster and more effectively. Albani explains that he and Boccaletti both reached a point of frustration at the lack of good quality data and software solutions to help decision makers in the corporate world and the public sector. "With Alessandro's research, we had something that was unique in terms of quality and scientific reliability," Albani reflects. With the increasing urgency of the climate crisis and the increasing resolve of civic and business leaders to act on it—culminating in COP26 in Glasgow in November 2021—the founders saw a need to make Alessandro's scientific research available to a wider audience. The company launched in March 2021; at COP26, the World Economic Forum recognized Chloris as a Top Innovator in the Uplink Carbon Markets Challenge.

Seeing the forest biomass for the trees: a new approach to measuring carbon

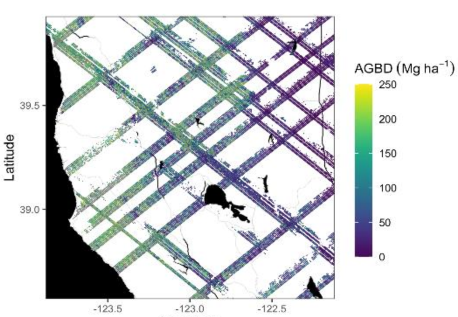
Chloris Geospatial's innovation draws on Baccini's two decades of research as a scientist, first at FAO, then at Woods Hole Research Center and, finally, at Boston University. During this time he conducted extensive field work and measurements in 20 countries, eventually developing the technology and methodology to measure carbon in vegetation using remote sensing data.

To measure carbon in vegetation, one must know its biomass. Biomass is the density or total dry weight of organic matter in a given area. The most accurate measurement of a tree's biomass is to cut it down and weigh it. Instead, field researchers use allometric models to estimate biomass based on measurements of a tree's basal diameter (or area), height, canopy diameter, or canopy volume. The amount of carbon in the biomass is approximately 50 percent of the dry weight. In measuring carbon, scientists generally focus on aboveground carbon, even though terrestrial carbon includes the carbon in the soil, because photosynthesis happens above ground, and that is process that drives carbon sequestration or the absorption of carbon dioxide from the atmosphere. The point of measuring above-ground carbon is to measure the *change in carbon sequestration* over time. Aboveground biomass is also where dramatic change happens; while carbon in the soil more or less stays in the soil, carbon in aboveground biomass changes constantly as vegetation grows, dies, burns, or is removed altogether by logging. Aboveground biomass is also measurable and the source of belowground carbon. So when measuring carbon sequestration, it makes sense to use aboveground biomass as the indicator.

The challenge then is scaling the aboveground biomass estimate from one tree to a whole area. Traditionally, forestry resorted to tree counts at a plot level that would then be extrapolated across a larger area. But this is not a reliable assessment of tree count nor does it reflect biomass, as it doesn't track variations in the size or height of the vegetation. Moreover, there is no single standard of classification across regions and jurisdictions on what counts as a tree (is a tree 3 feet high, 10 feet?), especially given the wide diversity of tree and plant species across the planet. Currently, different jurisdictions use different forest definitions and fieldwork protocols, making accountability and reliable comparison across jurisdictions impossible. Field data also has limitations in the spatial and temporal focus of the plot inventories. The extrapolation of a plot sample to a wider area might be statistically sound and yet miss altogether events that are sudden or very localized. A single destructive event like a forest fire might instantly wipe out an area of vegetation without field monitoring registering it for years. A clearcut plot may not register either if it does not happen to be adjacent to the study area; the extrapolation could credit the whole region with tree coverage without registering specific gaps. And many areas of densely forested land are altogether inaccessible to field research. Sometimes, a sudden localized event can have a dramatic impact on the overall biomass trend. For example, a catastrophic storm on October 29, 2018 knocked down 8 million cubic meters of wood in the northeastern Italian Alps. Satellite data was able to register and quantify the impact of this localized event. The storm damage in Tretino-Alto Adige resulted in an aboveground biomass loss of 5 metric megatons of carbon dioxide equivalent and 3 metric megatons CO_2e loss in Veneto in 2018, reversing the region's prior gains.



Remote sensor imaging from space introduces a more reliable—consistent, systematic, and global—means of surveying vegetation across the globe. LiDAR (light detection and ranging) technology in particular delivers an accurate tool for biomass assessment. Using laser and radar, LiDAR returns a measure of the varying height of land vegetation, measuring not just the extent of canopy cover but also its topography. Chloris uses a combination of IceSAT (Ice, Cloud, and Land Elevation Satellite) LiDAR measurements for its 5-km dataset and GEDI (Global Ecosystem Dynamics Investigation, an instrument installed at the International Space Station) LiDAR for its 30-meter dataset. GEDI is the

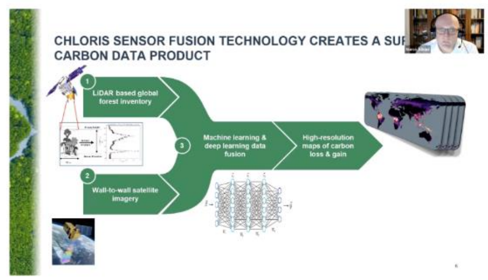


Example of aboveground biomass density predictions from the GEDI Level-4A footprint highest resolution and densest sampling of any LiDAR instrument in orbit today. It delivers approximately 30-meter footprint samples spaced every 60 meters along its track and 600 meters across track.

LiDAR takes measurements with great accuracy at a sample point in time. But these measurements number in the millions, with some data offering better information than others depending on factors such as cloud cover. Moreover, these measurements are not repeated in the same place and not available for long time series.

Using machine learning to transform biomass data into environmental insights

To transform LiDAR data into environmental insights across space and time, it is necessary to fill in the blanks. Only when these millions of data points are plotted on a map and in time series does a picture of carbon dynamics emerge. Chloris cross-references LiDAR and satellite imaging to achieve such insight.



Chloris Sensor Fusion technology applies machine learning algorithms to satellite imagery in order to generalize the spot measurements of biomass taken from LiDAR sensors across space and time. Essentially, the machine learning and deep learning algorithms connect the dots among millions of LiDAR snapshots and synthesize them into maps by reference to wall-to-wall optic imagery of the earth produced by the satellites. By referencing satellite images, Baccini and team are able to estimate the carbon density stored at a specific location over a year. The 5-km map uses imagery from Modis Terra and Aqua, the moderate resolution imaging spectraradiometer. Chloris' higher resolution 30-meter commercial product uses a combination of Landsat 8, Sentinel-2 optical imaging and other instruments at high spatial resolution.

Sentinel-2 satellite for wide-swath, high-resolution multispectral imaging

Machine learning also helps connect the temporal dots; the algorithm analyzes all datapoints over the year, selects the best images unimpeded by cloud cover, and synthesizes them into an annualized picture. With the Biomass Map, Chloris has taken nearly 20 years of such annualized biomass density maps and compiled them into a time series displaying the trajectory of biomass at each specific location as it evolves over time. If the biomass is increasing, this is a reliable indicator that CO_2 is being removed from the atmosphere.

The Chloris Biomass Map is thus the product of two sources of data—LiDAR-based global forest inventory and wall-to-wall satellite imagery fused through deep machine learning to produce maps of carbon loss and gain over time. Chloris is continually testing and finetuning the accuracy of these maps by reference to on-the-ground field data. “The project-level data is validating our estimated data,” says Albani. “There is good agreement even at a detailed scale with a moderate-level dataset.” In addition to validating by comparison, the machine learning model also has the capacity to absorb new inputs such as field data, continually refining its estimates. One specific application of field data that Chloris envisions is to refine carbon stock estimates beyond the current 50 percent average applied to all vegetation. Biologically diverse old forest has higher carbon stock than a plantation, for example. Old growth has the highest stock. One could look at the degree of vegetational diversity and the different levels of carbon in high or less biodiverse vegetation could be tracked accordingly. Being able to distinguish these could recognize and help incentivize forestry practices such as selective cutting that help the existing forest regenerate itself. Ultimately, Sensor Fusion technology could be extended to monitor other elements of natural capital too, such as biodiversity and water retention.

Putting nature on the balance sheet

Chloris Sensor Fusion technology supersedes traditional measures of forest carbon in its accuracy, scale, and speed. “The industry practices around carbon measurements in land and forest are still very much stuck in the old way of doing things,” says Albani. “The industry is still fundamentally relying on land use and land cover measurements and then applying carbon factors to the change in land cover.” This correlation is inaccurate and unmerited, dependent as it is on assumptions of what qualifies as tree cover and how much carbon that coverage contains. Besides its unreliability as a carbon change indicator, the land cover method also lacks the flexibility to make it a useful tool for measuring impact at the scale and speed needed for business and government decision making.

Chloris technology answers critical questions for decision makers: *Is what we are doing making a difference compared to what would have happened otherwise? Is this project actually making a change in the landscape or are we simply displacing a problem somewhere else?* The first question is one of additionality, explains Albani—are you adding value?—while the second checks for carbon leakage—did your carbon gain result in an adjacent carbon loss? Insight on these questions can help project developers and investors at every stage of a project. At the planning stage, analysts can scope projects more quickly, using carbon dynamics insight to determine where to site a project or how to design the project for more carbon capture. As the project progresses, managers can measure progress and pivot their approach as they identify which tactics are yielding results. To reduce costs, leaders can use the data for stratification to target areas for higher-cost investment. Investors can evaluate and compare nature-based solutions to target the most effective use of their capital. Businesses can assess the carbon impact of their supply chains, monitoring whether the production of their commodities is improving or getting worse. And companies can track their progress toward voluntary carbon targets.

As a flexible tool for carbon accounting, Chloris Sensor Fusion technology introduces a paradigm shift in how we look at natural resources. The ability to measure carbon impact introduces the concept of nature as an asset whose appreciation or depreciation may be tracked like capital on a balance sheet. Current financial accounting

> "We are under the belief that knowing the truth about natural capital will matter." Marco Albani, Chloris Geospatial

omits natural assets altogether, as if these resources were infinitely available for exploitation. We know better, but our accounting has not kept up. Leaders and environmental stewards can now say, "We have an endowment of wealth from nature; are we shrinking or growing it, and by how much?" By putting nature on the balance sheet, governments and businesses can adopt a broader definition of wealth that takes into precise account nature as a finite and depreciating resource. "If we are destroying natural capital in order to create income, we should at least know it," explains Albani. "Ideally we shouldn't do it but in the cases where we might have to, at least we can take full account of what's happening." By providing the geointelligence to measure natural assets, Chloris Geospatial hopes to drive policy and investment decisions for a sustainable and prosperous future.

About Chloris Geospatial

Chloris Geospatial provides innovative measurements of natural capital that use cutting-edge remote sensing, machine learning, and ecological science. Its sensor fusion technology can directly measure carbon stock, gains and losses with quantified uncertainty at the pixel level everywhere in the world.

Resources

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