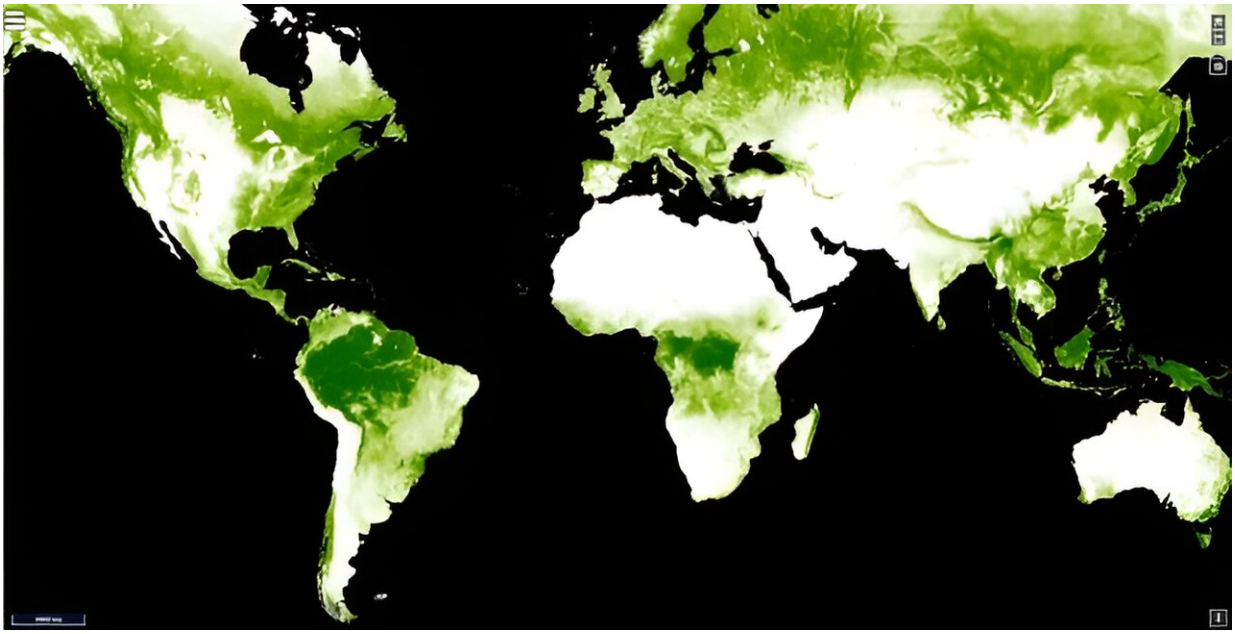
How vegetation could impact the climate of exoplanets

September 2 2024, by Evan Gough



This image made of satellite data shows the regions of Earth covered by forests with trees at least five meters (16.5 ft.) tall. Image Credit: NASA/LandSat

The term "habitable zone" is a broad definition that serves a purpose in our age of exoplanet discovery. But the more we learn about exoplanets, the more we need a more nuanced definition of habitable.

New research shows that vegetation can enlarge the habitable zone on any exoplanets that host plant life.

Every object in a solar system has an albedo. It's a measurement of how much starlight the object reflects back into space. In our solar system, Saturn's moon, Enceladus, has the highest albedo because of its smooth, frozen surface. Its albedo is about 0.99, meaning about 99% of the sun's energy that reaches it is reflected back into space.

There are many dark objects in space with low albedos. Some say that another of Saturn's moons, Iapetus, has the lowest albedo.

Earth, the only living planet, has an albedo of about 0.30, meaning it reflects 30% of the sunlight that reaches it back into space. Many factors affect the albedo. Things like the amount of ice cover, clouds in the atmosphere, land cover vs. ocean cover, and even vegetation all affect Earth's albedo.

We live in an age of exoplanet discovery. We now know of more than 5,000 confirmed exoplanets, with many more on the way. Though all planets are interesting scientifically, we're particularly interested in exoplanets that are potentially habitable.

A team of Italian researchers is examining exoplanet habitability through the lens of vegetation and albedo. Their work is in a paper accepted for publication in the *Monthly Notices of the Royal Astronomical Society* titled "Impact of vegetation albedo on the habitability of Earth-like exoplanets." The lead author is Erica Bisesi, a Postdoctoral Researcher at the Italian National Institute for Astrophysics' Trieste Astronomical Observatory.

"Vegetation can modify the planetary surface albedo via the Charney mechanism, as plants are usually darker than the bare surface of the continents," the researchers write in their paper. Compared to a dead planet with bare continents, an exoplanet with vegetation cover should be warmer if they're both the same distance from similar stars.

The Charney mechanism is named after Jule Charney, an American meteorologist who is considered by many to be the father of modern meteorology. It's a feedback loop between vegetation cover and how it affects rainfall.

In their work, the researchers updated the Earth-like Surface Temperature Model to include two types of dynamically competing vegetation: grasslands and forests, with forests included in the seedling and mature stages.

"With respect to a world with bare granite continents, the effect of vegetation-albedo feedback is to increase the average surface temperature," the authors explain. "Since grasses and trees exhibit different albedos, they affect temperature to different degrees."

Since grasses and trees affect albedo differently, vegetation's effect on planetary albedo is linked to the outcome of their dynamic competition. "The change in albedo due to vegetation extends the habitable zone and enhances the overall planetary habitability beyond its traditional outer edge," the authors write.

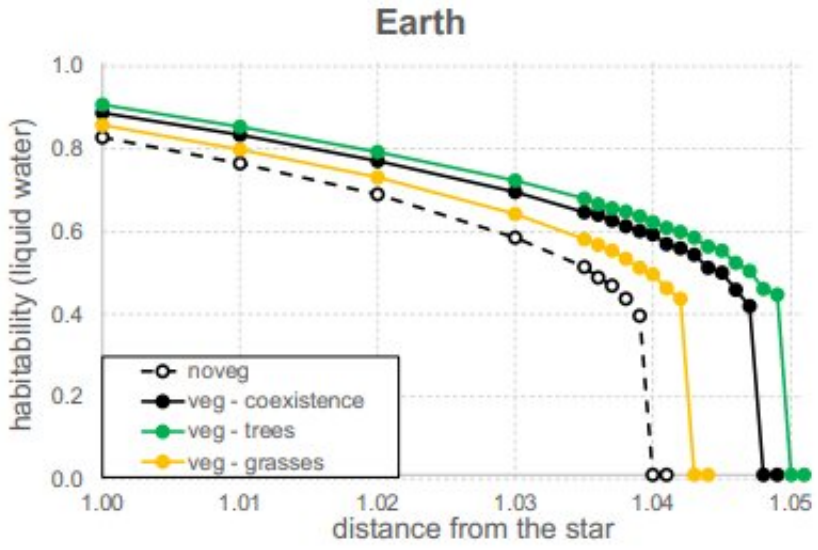
The researchers considered four situations:

- Complete tree dominance (forest worlds).
- Complete grass dominance (grassland worlds).
- Tree/Grass coexistence.
- Bi-directional worlds

In a bi-directional world, vegetation converges to grassland or to forest, depending on the initial vegetation fractions. In these worlds, seed propagation across latitudes widens the region where forests and grasslands coexist.

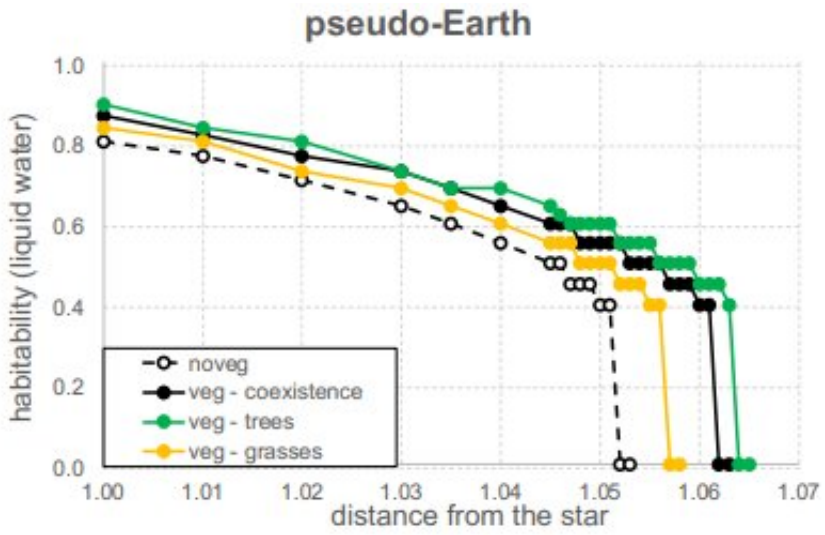
The researchers found that vegetation cover lowers a planet's albedo and warms the climate, nudging the outer limit of the habitable zone. However, they also arrived at more specific results.

They found that the outcome of dynamic competition between trees and grasses affected how vegetation is distributed across latitudes. "The achieved temperature-vegetation state is not imposed, but it emerges from the dynamics of the vegetation-climate system," they explain.



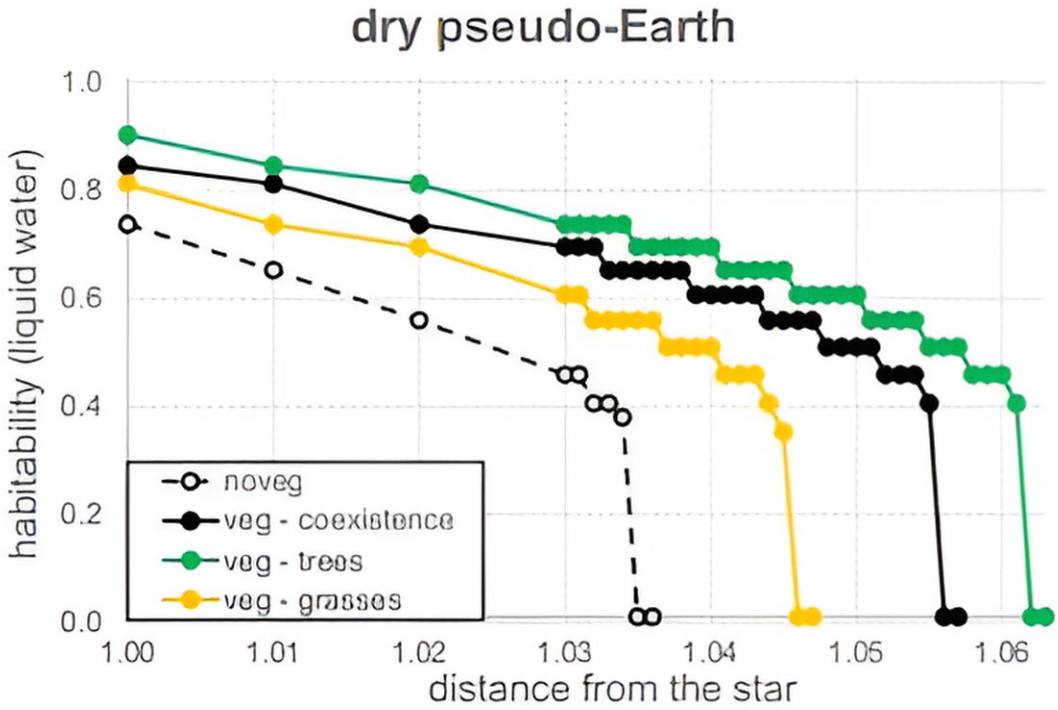
This figure from the research shows how Earth's liquid water habitability index is shifted outward by different vegetation regimes. It's based on Earth's modern distribution of continents. Credit: Bisesi et al. 2024.

The researchers worked with the idea of a 'pseudo-Earth." The pseudo-Earth has a constant fraction of oceans at all bands of latitude, affecting the distribution of continents and vegetated surfaces relative to the equator, where most of the sun's energy strikes the planet.



This figure from the research shows how a pseudo-Earth's liquid water habitability index is shifted outward by different vegetation regimes. It's based on an equal distribution of oceans at all bands of latitude. Credit: Bisesi et al. 2024.

The researchers also worked with a hypothetical dry pseudo-Earth. On this Earth, ocean cover is limited to 30%, while the Earth and the pseudo-Earth both have 70% ocean cover.



The simulated dry pseudo-Earth has less ocean coverage than Earth, meaning there's more surface area for vegetation to cover. Credit: Bisesi et al. 2024.

The team reached some conclusions about vegetation cover, albedo, and habitability.

The more continents a planet has, the greater the climate warming effect from vegetation. When the simulations resulted in a grass-dominated world, the effect was weaker because grass raises albedo. When the simulations resulted in a forest-dominated world, the effect was greater.

The researchers' key point is that none of this is static. Outcomes are driven by the competition between grasslands and forests for resources, which in turn is driven by the average temperature in each latitudinal band. "In general, thus, the achieved temperature-vegetation state is not

imposed, but it emerges from the dynamics of the vegetation-climate system," they explain.

This is especially pronounced on the dry pseudo-Earth. Because there is so much land cover, vegetation has an even stronger effect on albedo and climate. "However, the ocean fraction cannot be too small, as in this case, the whole hydrological cycle could be modified," the researchers add.

Overall, vegetation's effect on albedo and climate is small. But we can't dismiss its effect on habitability. Habitability is determined by a myriad of factors.

This issue is very complex. For instance, on a planet where grasslands and forests coexist, external factors like stellar luminosity and orbital variations can be buffered depending on where the continents are and how much their vegetation affects albedo purely by location.

The authors consider their work as a basic first step in this issue. They only included certain types of grasslands and forests, didn't include the relative availability of water, and didn't include atmospheric CO_2 concentrations.

"The dynamics explored here are extremely simplified and represent only a first step in the analysis of vegetation habitability interactions." they write. "Future work will also include a simplified carbon balance model in the study of planetary habitability."

"This endeavor should be seen as a first step of a research program aimed at including the main climate-vegetation feedbacks known for Earth in exoplanetary habitability assessments," they write.

More information: E Bisesi et al, Impact of vegetation albedo on the

habitability of Earth-like exoplanets, *Monthly Notices of the Royal Astronomical Society* (2024). DOI: 10.1093/mnras/stae2016

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