IS IT POSSIBLE TO USE GPS TO COMBAT CLIMATE CHANGE?

Teresa Fang

Teresa Fang was selected as the winner of the 2024 *Broad Street Scientific* Essay Contest. Her award included the opportunity to interview Dr. Richard McLaughlin, Professor of Mathematics at the University of North Carolina at Chapel Hill.

Despite the Global Positioning System (GPS) being well known, few are aware of an alternative use of its signals. Aside from providing directions to the nearest café or restaurant, GPS can revolutionize remote sensing, serving as a tool to predict natural disasters and combat climate change.

GPS is a tool for remote sensing. At its core, remote sensing is communication through electromagnetism. It relies on two things: a transmitter and a receiver. A satellite's transmitter will encode a message through various bands of electromagnetic frequencies using modulation, changing data into waves [1]. A receiver will then pick those up and transform the waves back into analytical data. Depending on factors like distance apart, size of antennas, types of electromagnetic transmission, bandwidth, or limiting power, different kinds of data can be measured and transmitted.

At present, GPS consists of a network of 31 broadcasting satellites orbiting Earth at an altitude of around 20,000 km. While normal radar satellites have both their receiver and transmitters on the satellites, GPS has receivers on the ground, listening and interpreting microwave satellite transmission [1]. This means that at any point on the Earth's surface, you are in the range of at least four satellites tracking the intersection of three physical dimensions, along with time, through trilateration. In an everyday example, your phone is the receiver to those four satellites' transmitters to pinpoint your real-time location on Earth.

But what makes GPS an ideal tool to revolutionize remote sensing? After all, GPS is just a type of microwave radar system with a different scattering geometry than other systems, and microwave radar has been used for years to detect changes in Earth's surface.

GPS reflectometry is one of the three techniques that have untapped potential for studying and combating climate change [2]. The two others are occultation, which measures the vertical gradient of the atmospheric index, and scatterometry, which scatters signals over targets like water to measure wind properties [3][4]. GPS signals are circularly polarized L-band signals (1-2 GHz range, at 19 or 24 cm specifically for GPS), which means they are unaffected by cloud cover and sunlight, thus making it easier to measure strong versus weak signals from surfaces with large changes in dielectric constants, such as wet soil or sea ice [5]. This system allows researchers to measure changes in the frequency, amplitude, or phase of the interference pattern of a reflected surface to draw observations and collect pinpointed data quickly.

But rather than just having satellites track climate change, satellites may contribute to "solving" climate change through the bidirectional reflectance distribution function (BRDF). The BRDF

$$f_r(w_i, w_r)$$

determines a surface's reflected energy in terms of incoming and reflected radiance [6]. Using the measured BRDFs of a known surface, BRDF can be applied to a much larger scope to image a larger surface, such as Earth. By adding more variables to the BRDF, we can potentially evaluate the parameters of a climate change model, i.e. with a multivariable function

$$f_r(w_i, w_r, T, V_w, V_c, M_s)$$

where T represents temperature, V_w represents wind speed, V_c represents water current speed, M_s represents soil moisture, etc.

GPS signals can provide the necessary information, in the form of microwaves, to model such a function. As a pioneering technique, GPS reflectometry is a promising approach to measuring and modeling hydrologic effects, such as icebergs or Arctic sea ice [6]. As a tool to combat climate change, these satellites give us an overhead and underwater view to make models, find melt rates, and potentially find ways to offset rising sea levels in the long run. While normal radar satellites have difficulty measuring ice thickness, GPS signals have long wavelengths to penetrate that canopy. If we can also measure the levels of greenhouse gases in the atmosphere, we could evaluate the correlation of greenhouse gases with the rate of sea ice melting and develop predictability models using the multivariable BRDF to mimic both short-term and long-term climate changes.

Although several other remote sensing techniques and instruments can retrieve the same information, the GPS reflection technique is cost-effective. GPS recycles signals that already exist in the ionosphere, so there is no need for additional satellites or expensive microwave transmitters, such as the passive radiometers and active radars that NASA and CERN have been launching. For example, NASA's eight-satellite CYGNSS constellation cost $152 million to study Earth's hydrology, while CERN's two-satellite Sentinel 1 constellation cost $385 million for the same purpose [8][9].

GPS reflectometry may be an avenue to revolutionize future satellite missions, as this technique is relatively cheap and can provide data complementary to existing data, filling gaps in our knowledge on select aspects. Launching constellations of GPS instruments would be interesting, as GPS constellations have a high temporal resolution or temporal repeat period. With multiple satellites collecting data over a location at the same time, frequently updated data are readily available, making the creation of both predictability models and near-real-time spatial resolution maps easier. This means people in affected communities can have more time to evacuate in times of disaster as forecasting is more accurate. As more and more research is being done into GPS reflectometry, finding alternatives to dealing with climate change may be less of a distant dream and more of an innovative reality.

[1] Schauer, Katherine. (2020, October 6). Space Communications: 7 Things You Need to Know. NASA. https://www.nasa.gov/missions/tech-demonstration/space-communications-7-things-you-need-to-know/#:~:text=At%20its%20simplest%2C%20space%20communications

[2] Baier, M. (n.d.). GPS occultation, reflectometry and scatterometry (gors) receiver technology based on COTS as quintessential instrument for future tsunami detection system. GPS Reflectometry. https://www.gitews.de/en/gps-technology/gps-reflectometry/#:~:text=GPS%20scatterometry%20and%20reflectometry%20are,compensates%20for%20the%20low%20signal

[3] Eyre, J. R. (2008, June). An introduction to GPS radio occultation and its use in numerical weather prediction. In Proceedings of the ECMWF GRAS SAF workshop on applications of GPS radio occultation measurements (Vol. 1618).

[4] Center for Ocean-Atmospheric Prediction Studies (COAPS). (n.d.). Scatterometry - Overview. Scatterometry & Ocean Vector Winds. https://www.coaps.fsu.edu/scatterometry/about/overview.php

[5] Chew, C. (2022). Water makes its mark on GPS signals. Physics Today, 75(2), 42–47. https://doi.org/10.1063/Pt.3.4941

[6] Wynn, C. (2015, October 7). A basic introduction to BRDF-based lighting. Princeton University. https://www.cs.princeton.edu/courses/archive/fall06/cos526/tmp/wynn.pdf

[7] Schild, K. M., Sutherland, D. A., Elosegui, P., & Duncan, D. (2021). Measurements of iceberg melt rates using high-resolution GPS and iceberg surface scans. Geophysical Research Letters, 48(3). https://doi.org/10.1029/2020gl089765

[8] Harrington, J. D. (2023, July 26). NASA selects low cost, High Science Earth Venture Space System. NASA. https://www.nasa.gov/news-release/nasa-selects-low-cost-high-science-earth-venture-space-system/

[9] Clark, S. (2014, April 2). Europe's Earth Observing System ready for liftoff. Soyuz launch report. https://spaceflightnow.com/soyuz/vs07/140402preview/#:~:text=Levrini%20said%20the%20Sentinel%201A,or%20%2492%20million%2C%20he%20said