# The FROst Dynamics Observatory (FRODO) Concept


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The presence or absence of liquid water is a key control on metabolic and hydrologic processes in high latitude boreal and Arctic ecosystems. For the majority of the year, significant amounts of available water are frozen, thus inhibiting plant transpiration and soil microbial activity. During the short growing season, land-atmosphere exchange of carbon is significant —both as $CO_2$ uptake by vegetation, and as $CO_2$ and $CH_4$ release from microbial aerobic and anaerobic respiration, respectively, in soils. The transitional "shoulder" seasons are periods when liquid water availability is generally increasing (springtime) or decreasing (autumn) as water transitions between liquid and solid phases. Recent results have shown that the autumn transition and the associated freezing of tundra soils may extend over long periods and relate to extended periods of $CH_4$ release, affecting the annual carbon budget significantly.

Scientists and global climate models disagree as to how future warming and longer growing seasons will impact the high latitude carbon cycle and whether these ecosystems will be a net source or sink of atmospheric carbon. One of the first steps to ending this debate is quantifying the length of the growing season and transition periods at appropriate spatial and temporal scales. There is little known about how landscape heterogeneity affects the timing and duration of the freeze/thaw transitions, as the majority of remote sensing products are coarser (25-50 km) than the landscape-scale processes that might drive the freeze/thaw transitions. As transitioning between seasons and associated phase of water occurs rapidly, observations with high temporal resolution are also needed.

Developing an observational system to quantify freeze/thaw state in the high latitudes is challenging, since both high temporal and spatial resolutions are required. A constellation of small satellites could provide measurements with high temporal repeat, but putting several transmitters in orbit would be cost prohibitive. However, an inexpensive way of monitoring changes in the Earth's surface exists in the form of Global Navigation Satellite System (GNSS)-Reflectometry (GNSS-R). GNSS-R leverages the existing constellations of transmitters already in orbit, such that an observing system as described above could be possible, requiring only receivers.

Here, we describe a FROst Dynamics Observatory (FRODO), in which GNSS-R would be used to quantify the time series landscape freeze/thaw state across the high latitudes. To demonstrate the potential of such a system, we have utilized the radar receiver from NASA's SMAP satellite as an on-orbit GNSS-R receiver. We present observed seasonal differences in these data from both the SMAP radar receiver and from ESA's TechDemoSat-1 (TDS-1). We examine associated changes in the freeze/thaw state as observed using these systems and ground station measurements. TDS-1 and the SMAP radar receiver enable assessment of this measurement technique; an appropriately designed constellation of dedicated Earth-orbiting receivers could provide such data at the required temporal and spatial resolutions.