**Harrison Hague**

**Literature Review**

[TanDEM-X satellite image - Changes in permafrost landscapes - AWI](https://www.awi.de/en/focus/permafrost/tandem-x-satellite-image-changes-in-permafrost-landscapes.html)

* More profound permafrost changes at high latitudes
* 25% of the Northern Hemisphere contains permafrost, Satellite image analysis is the most viable way of analysing it
* Transmitted microwaves (active sensors?) can be used to see if water freezes to the bottom
* Thermoskarst lakes, can thaw in a few decades- evidence that thawing can be sudden at a regional level under certain conditions – Dr Guido Grosse
* Helmholtz research alliance, TanDem-X data – Ground subsidence (sinking/caving of land) analysed with DlnSAR method (Differential SAR Inteferometry). Estimations hampered by other surfaces e.g moss moisture, vegetation etc... so they do some measurements on site. – If they used more SAR images (currently requires at least 2 SAR images of a location) maybe would lessen the vegetation effect on results? -Tandem-L

[Studying permafrost by integrating satellite and in situ data in the northern high-latitude regions | SpringerLink](https://link.springer.com/article/10.1007/s11600-019-00276-4)

* GRACE – Gravity and Climate Experiment – Able to measure secular gravity changes related to near-surface mass changes
* Measure permafrost change through gravity field change, surface temperature, glacial isostatic adjustment
* Process of permafrost change releases greenhouse gasses (C02 & Methane)
* High correlation between the secular trends of greenhouse gasses (C02), temperature and equivalent water thickness in permafrost active layer (active layer is the surface layer that thaws in summer and freezes in winter)
* Groundwater storage because of permafrost thawing increasing by 3.4-4.4cm a year
* The permafrost is frozen soil, sediment or rock that remains under 0 °C for at least two consecutive years (Brown et al. [1998](https://link.springer.com/article/10.1007/s11600-019-00276-4#ref-CR4))
* The talik is an unfrozen ground layer that lies below the active layer and above the permafrost
* Soils in the Arctic permafrost region are estimated to hold about twice as much carbon as the atmosphere (Hugelius et al. [2011](https://link.springer.com/article/10.1007/s11600-019-00276-4#ref-CR15)) -- The permafrost contains 850 gigatonnes of frozen carbon (i.e. dry ice) that is much more than the total of the carbon currently contained in the earth’s atmosphere, much of which could be released in the form of methane (<https://nsidc.org/cryosphere/frozenground/methane.html>). C02 & Methane retain heat in the atmosphere contributing to global warming which contributes to permafrost melting = Infinite domino effect!?
* Thawing permafrost is a local geo-hazard e.g erosion, dame to infrastructure & a possible global crisis due to gas emissions
* Greenland Ice Sheet has very few ice-melting measurements between 2009-2012, removed from GRACE data
* More information about borehole stations can be found through the global terrestrial network for permafrost through <http://gtnpdatabase.org/> , where the following important data are available: surface temperature, ground temperature, active layer thickness, surface soil moisture and air temperature.
* A large amount of carbon was stored in the permafrost by a process that took thousands of years. Mixing of soil layers due to repeated freeze–thaw processes (Cryoturbation) in the active layer accelerates the burial process by mixing the carbon-rich organic soil from the surface down to the permafrost horizon (Zech et al. [2008](https://link.springer.com/article/10.1007/s11600-019-00276-4#ref-CR54))
* The surface temperature is a main component in the climate change and permafrost carbon feedback processes
* The release of CO2 in the seasonally frozen layer, i.e. the active layer is sporadically occurring but the biologic processes of release and consumption, is highly variable and not well understood nor measured at sufficient detail and scale for a meaningful conclusion at this time
* Obviously, the large areas of permafrost in Canada and Siberia are partially responsible for some of the carbon dioxide emissions into the atmosphere. Since the Carbon dioxide can originate from anywhere on the Earth, proving that the carbon is coming from the thawed permafrost need special measuring tool and looking at the isotopic signatures to see that the carbon is old or coming from recent carbon cycling.
* Article concludes that their study might confirm the permafrost carbon feedback process

[remotesensing-13-01217-v3.pdf](file:///\\lancs\homes\12\hagueh\Downloads\remotesensing-13-01217-v3.pdf)

* Studies related to Arctic greenhouse gas emissions in the context of permafrost degradation appear heavily underrepresented. New tools (e.g., Google Earth Engine (GEE)), methodologies (e.g., deep learning or data fusion etc.) and satellite data (e.g., the Methane Remote Sensing LiDAR Mission (Merlin) and the Sentinel-fleet) ware useful and can enable future studies to investigate greenhouse gas emission rates on larger spatial and temporal scales
* Page 5 – Table of permafrost related programs and networks
* The majority of studies (94%) is distributed across the Northern Hemisphere, whereas only a few articles (6%) investigated the Southern Hemisphere due to the confined distribution of permafrost in alpine regions for example, Andes and ice-free areas for example, South Shetland Islands in the Antarctic
* Studies related to thermal features/processes and atmospheric features and processes are underrepresented with only 7% and 4% of all reviewed publications, respectively
* long-term and large to circum-Arctic scale analyses of permafrost-related features are required to fully understand the current situation and future implications of degrading permafrost
* Studies related to Arctic greenhouse gas emissions are underrepresented and will likely be a heavy focus in the upcoming years. Especially the Sentinel-5P mission and the Methane Remote Sensing LiDAR Mission (Merlin) are hereby promising data sources for future analyses

[Frontiers | Progress and Challenges in Studying Regional Permafrost in the Tibetan Plateau Using Satellite Remote Sensing and Models | Earth Science (frontiersin.org)](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full)

* Microwave remote sensing can operate at all weather conditions useful for surface soil temperature, freeze/thaw state and surface deformation. Resolution is an issue can add uncertainties and microwave remote sensing methods are limited to detections in the upper soil layer within a few centimetres.
* Most algorithms ignore the effects of soil water content or use moisture measurements from on site.
* Tibetan Plateau is the largest alpine permafrost area in the world ([Ran et al., 2018](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B95); [Cheng et al., 2019](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B17))
* Small distribution of observation sights so satellite remote sensing has large potential
* Optical and near-infrared remote sensing with high spatial resolutions (<100 m) has been widely used to identify geological structures and landscapes associated with permafrost, e.g., hummock, thermokarst lakes, freeze/thaw boils, and surface classification, which can be used to infer the presence of underlying permafrost ([Panda et al., 2010](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B89); [Wang et al., 2014](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B118); [Niu et al., 2018](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full" \l "B86); [Ran et al., 2018](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B95); [Huang et al., 2020](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B41))
* Microwave remote sensing shows strong sensitivity to soil dielectric changes induced by landscape and particularly soil freeze/thaw state, and can operate under all-weather conditions ([Ulaby et al., 2014](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full" \l "B109));
* Useful Section – Permafrost Monitoring using Microwave remote sensing
* No methods to detect deeper soil freeze, A potential approach to overcome this limitation is to introduce lower frequency sensors such as P-band SAR for soil profile characterization ([Chen et al., 2019](https://www.frontiersin.org/articles/10.3389/feart.2020.560403/full#B13))
* Tibetan Plateau represents unique challenges because of its complex topology.
* Deeper soil remote sensing requires lower frequency surveys (such as P-band SAR) and multi-frequency observations (such as joint L- and P-band SAR) to enable soil vertical profile retrievals. These sensors and corresponding algorithms should be developed
* Expansion of on site sampling (Trip to Tibet!??)

[Satellite images reveal a climate crisis nightmare in Siberia (inverse.com)](https://www.inverse.com/science/permafrost-siberia-heat-wave)

* Discovery of methane being emitted, PULSE can be used to calculate methane emissions in the air
* Areas of elevated methane concentration can then be coincided with other features to determine what is causing them. In this case the methane coincided with large limestone formations which led to the discovery of the ‘Thermogenic’ methane, natural gas stored up under the permafrost

[Vanishing Permafrost | National Geographic Society](https://www.nationalgeographic.org/photo/permafrost-mirco-743-60768/)

* Lakes in Siberia are shrinking because the permafrost they are on is melting which causes the water to be drained deeper into the ground

[Satellites reveal thawing permafrost | UN-SPIDER Knowledge Portal](https://www.un-spider.org/news-and-events/news/satellites-reveal-thawing-permafrost)

* Remote sensing and climate models is the future of understanding and predicting the regression of permafrost and it’s consequences

[Permafrost Thaw in Siberia Creates a Ticking 'Methane Bomb' of Greenhouse Gases, Scientists Warn | Smart News | Smithsonian Magazine](https://www.smithsonianmag.com/smart-news/ticking-timebomb-siberia-thawing-permafrost-releases-more-methane-180978381/)

* “The story is simple,” the report concludes. “Climate change is happening faster than anticipated. One consequence—the loss of ice in the polar regions—is also a driver for more rapid global heating and disastrously rapid global sea level rise.”

[ESA - Satellites yield insight into not so permanent permafrost](https://www.esa.int/Applications/Observing_the_Earth/Space_for_our_climate/Satellites_yield_insight_into_not_so_permanent_permafrost)

* More about the artic turning from ‘a carbon sink to a carbon source’
* Annett Bartsch, the founder and managing director of b.geos, explained, “We can’t monitor permafrost as such from space. Although it’s a bit complicated, we can, however, use a lot of different types of satellite data along with in situ measurements and modelling to put together a picture of what is happening.

[ESA - Sentinel-2](https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2)

* Satellite data from the European Space Agency

Mylinks

[Pulse - GHGSat](https://pulse.ghgsat.com/)

* PULSE – Methane concentration map

[Unexpected future boost of methane possible from Arctic permafrost – Climate Change: Vital Signs of the Planet (nasa.gov)](https://climate.nasa.gov/news/2785/unexpected-future-boost-of-methane-possible-from-arctic-permafrost/)

* Abrupt thawing more than doubles previous estimates of permafrost-derived greenhouse warming

[Welcome to PERMOS](http://www.permos.ch/)

* PERMOS has been built up by several research institutes since the early 1990s followed by a 6-year pilot-phase 2000–2006. Since 2007 the network is officially implemented with a coordination office and secured long-term funding. The networks develop towards an operational monitoring service with a sustainable and congruent network.

[Permafrost and climate in Europe: Monitoring and modelling thermal, geomorphological and geotechnical responses - ScienceDirect](https://www.sciencedirect.com/science/article/pii/S0012825208001311?via%3Dihub)

* Old article on modelling permafrost, relevant to show how far satellite imagery has come and why that’s such a big opportunity

[The Permafrost Information System PerSys – An Open Access geospatial data dissemination and visualization portal for products from ESA DUE GlobPermafrost - CORE Reader](https://core.ac.uk/reader/162028130)

* An Open Access geospatial data dissemination and visualization portal for products from ESA DUE GlobPermafrost

<https://www.researchgate.net/profile/Claude-Duguay-2/publication/303722386_Remote_sensing_of_permafrost_and_frozen_ground/links/5968dd1a458515e9afa7a26d/Remote-sensing-of-permafrost-and-frozen-ground.pdf>

* Remote sensing of permafrost and frozen ground, unpublished?