
Arctic Methane and Permafrost Challenge (AMPAC)

An ESA and NASA collaborative community initiative


# Satellite Monitoring of the CH4 Component of the Permafrost Carbon Feedback


## Charles Miller

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**And the AMPAC Team**


ESRIN, Frascati  4th Carbon from Space Workshop  26 Oct 2022

https://cce.nasa.gov/methane_challenge.html

https://eo4society.esa.int/communities/scientists/arctic-methane-and-permafrost/


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# Summary & Outlook

Key elements for space-based monitoring of Arctic CH4 are in place or planned for launch by 2030 and will operate into the 2030s

New techniques will enable monitoring of total Arctic CH4 emissions as well as component fluxes from Hotspots, Lake Ebullition, and Wetlands

Increased understanding of cold season emissions possible via active atmospheric CH4 sensing and potential for mapping zero curtain extent and duration

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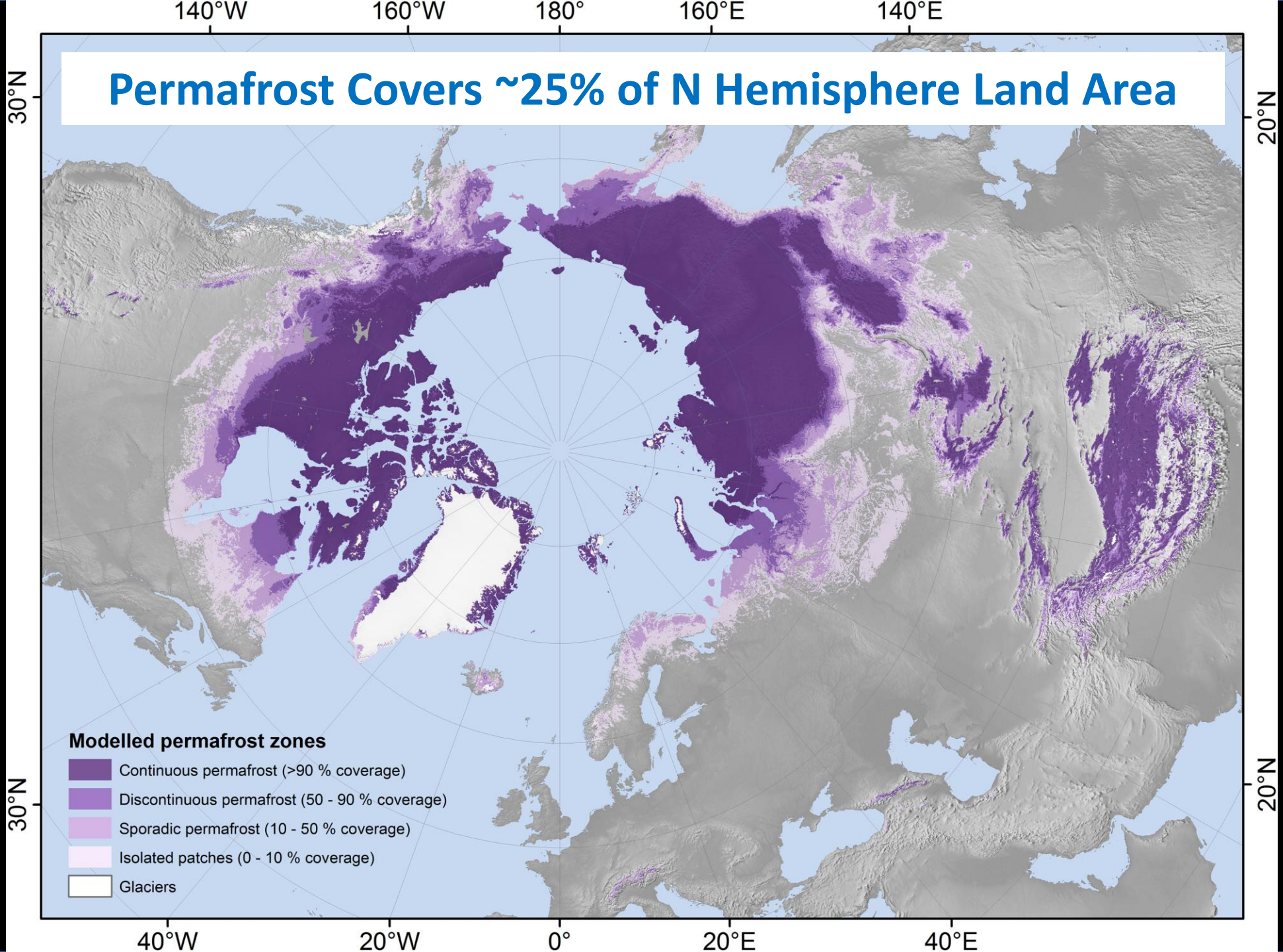
# Permafrost Covers ~25% of N Hemisphere Land Area



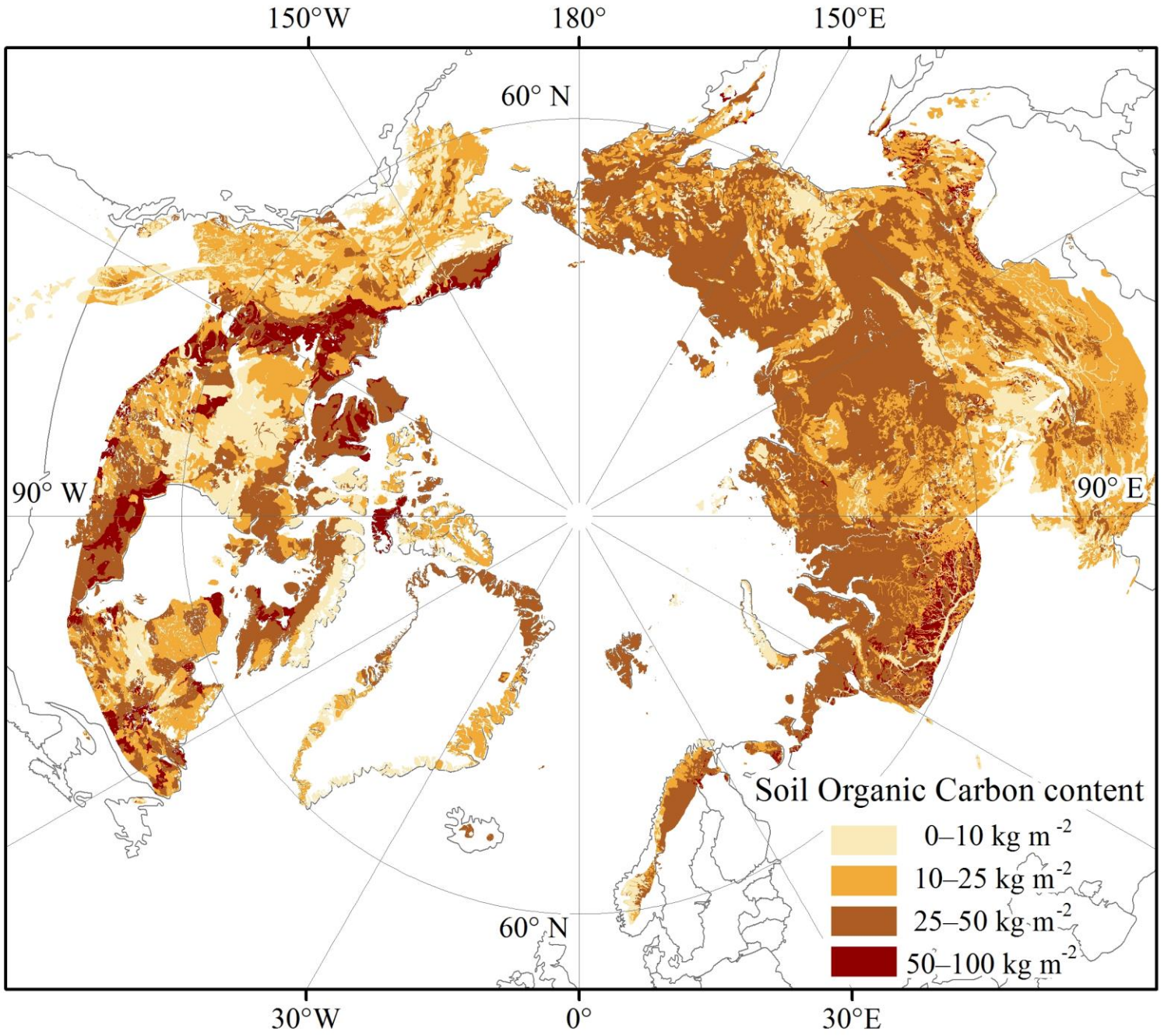

*Obu et al., Earth Sci Rev (2019)*

# Permafrost Stores Massive Amounts of Soil Organic Carbon

- 1100 GtC 0-3 m
- 600 GtC > 3 m deep
- 1700 GtC Total

**Anthropogenic Emissions**

- 2019: ~12 GtC
- Since 1850: ~420 GtC




*Hugelius et al., Earth Sys Sci Data (2013)*
*https://bolin.su.se/data/ncscd/*

# Thermokarst and Permafrost Degradation Are Exposing Previously Frozen SOC


Photo Credit: Rory Nichols

Photo Credit: Jonathon Newton, Washington Post

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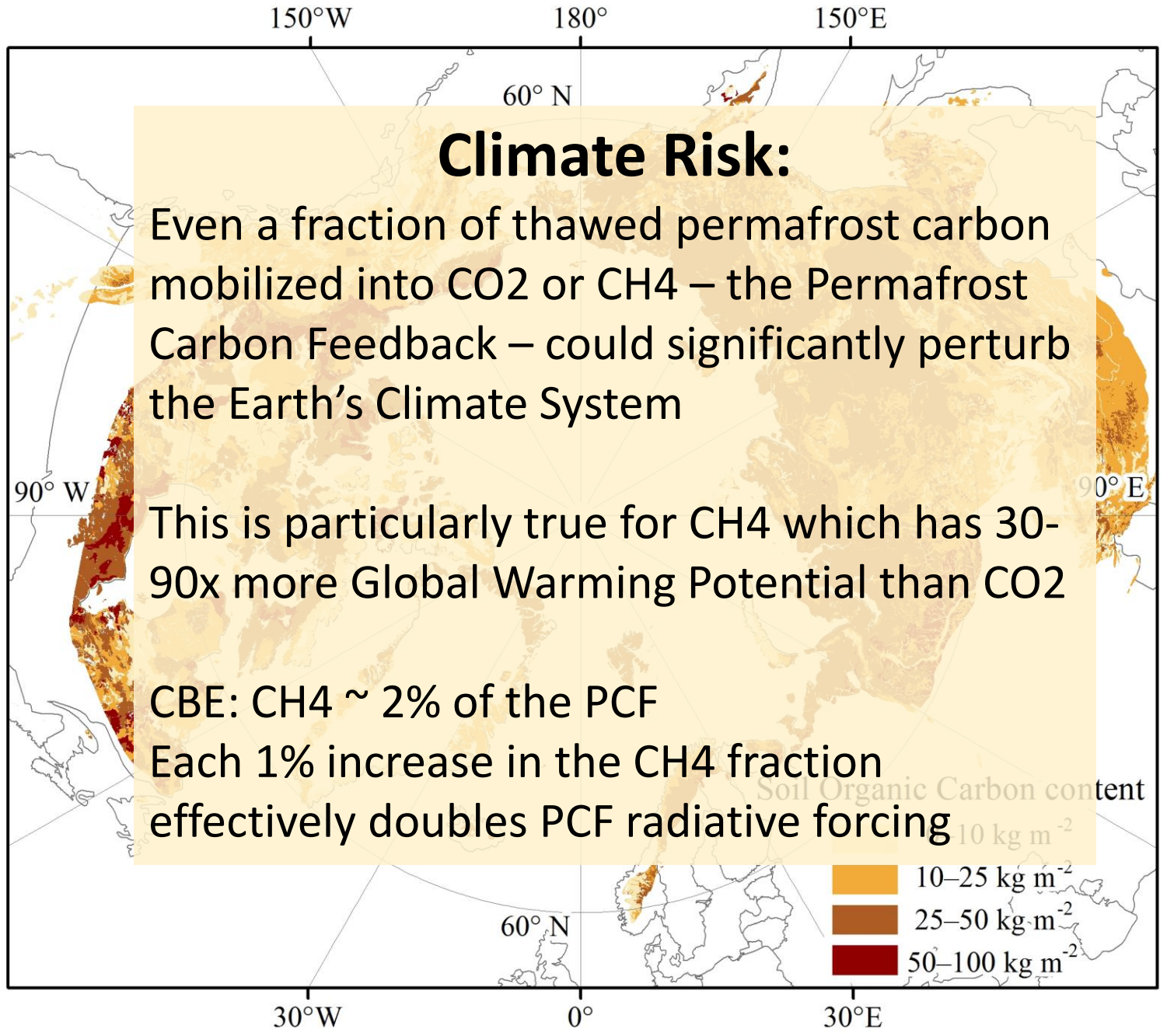



## Climate Risk:

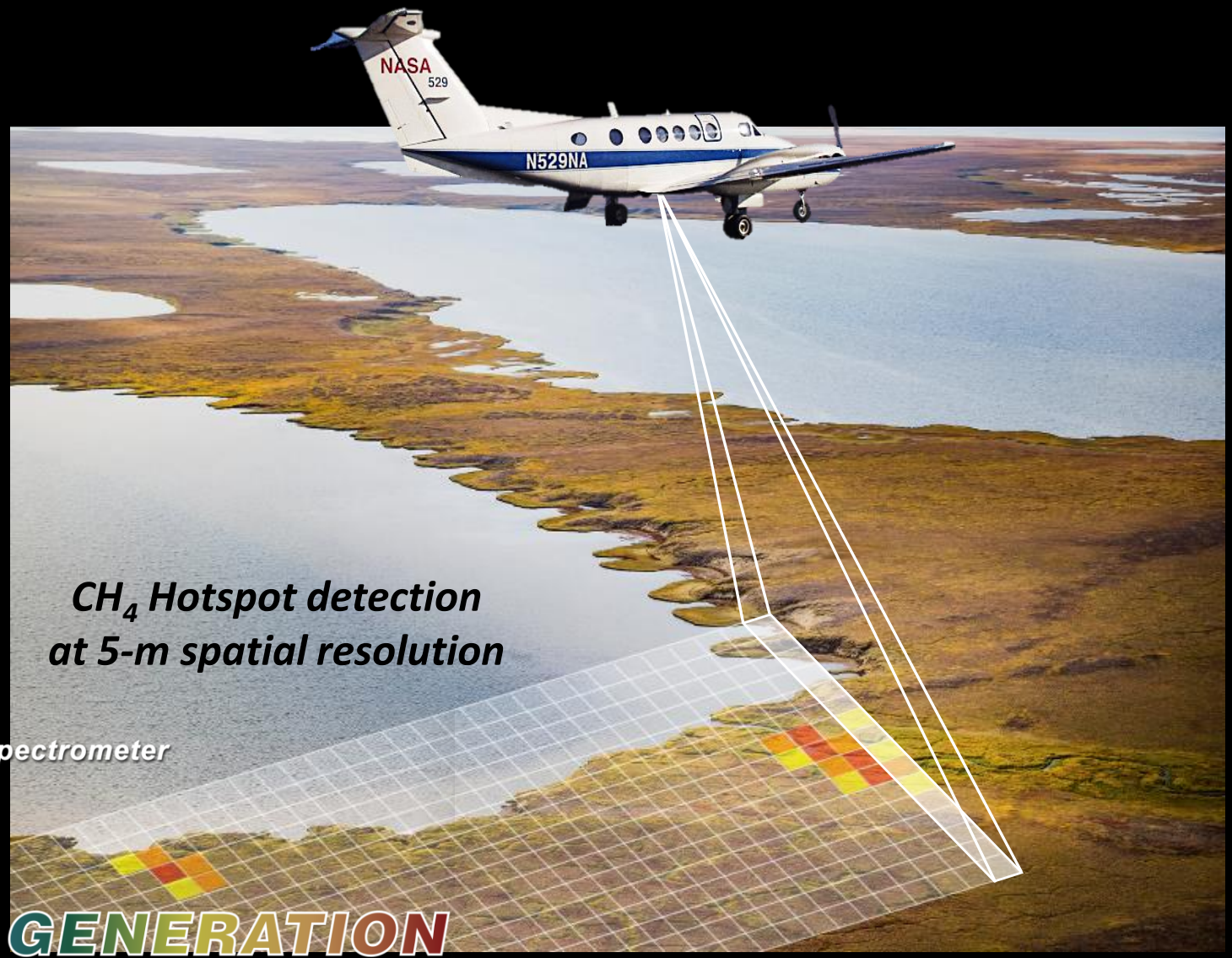
Even a fraction of thawed permafrost carbon mobilized into CO2 or CH4 – the Permafrost Carbon Feedback – could significantly perturb the Earth's Climate System

This is particularly true for CH4 which has 30-90x more Global Warming Potential than CO2

CBE: CH4 ~ 2% of the PCF
Each 1% increase in the CH4 fraction effectively doubles PCF radiative forcing

*Hugelius et al., Earth Sys Sci Data (2013) https://bolin.su.se/data/ncscd/*

# Breakthrough Science: Mapping Arctic CH4 Hot Spots with AVIRIS Imaging Spectroscopy




ABoVE
ARCTIC – BOREAL VULNERABILITY EXPERIMENT

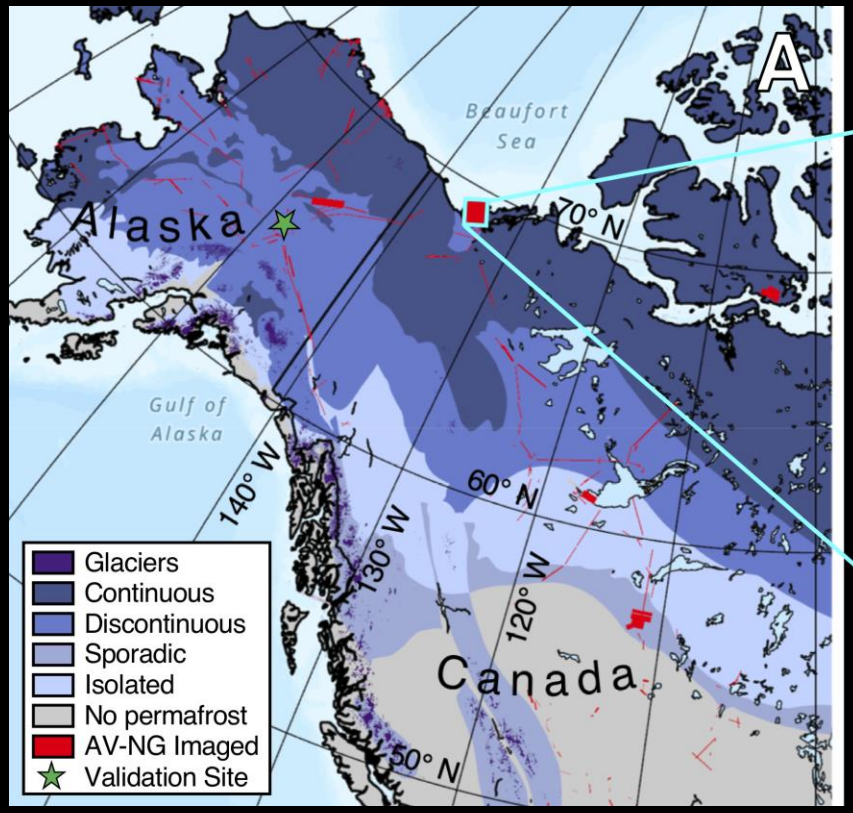
Airborne Visible / Infrared Imaging Spectrometer
AVIRIS
NEXT GENERATION

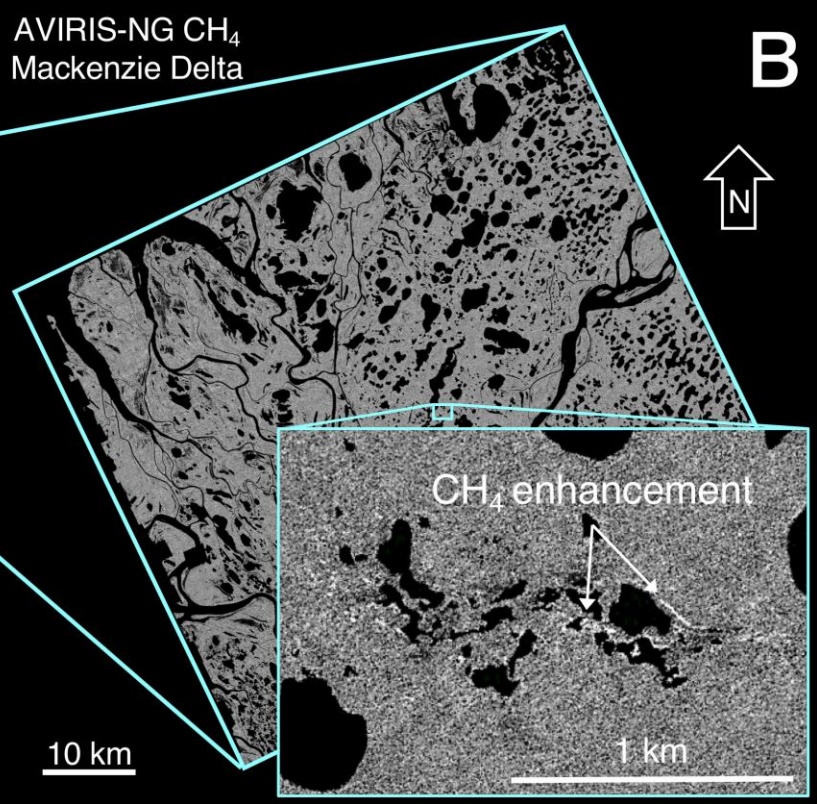
*Elder et al., Geophys Res Lett (2020)*
*Elder et al., Global Biogeochem Cycles (2021)*
*Baskaran et al., Environ Res Lett (2022)*

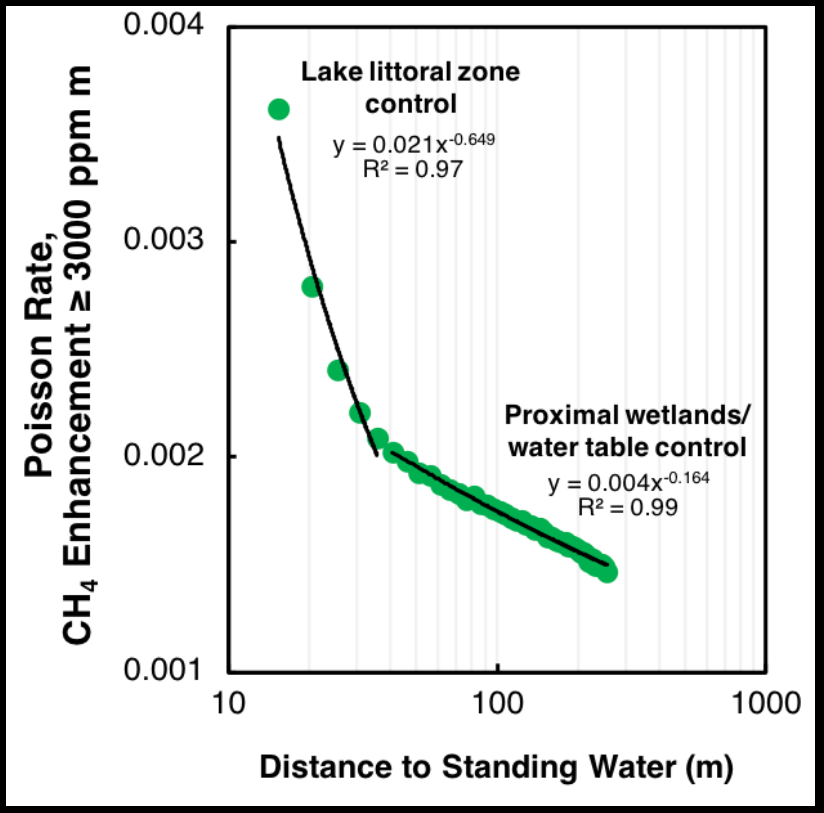
# **RESULTS**: ~5 million $CH_4$ hotspots detected at 5-m pixel resolution over ~120,000 km$^2$ between 2017-2022 (billions of observations)

ARCTIC – BOREAL VULNERABILITY EXPERIMENT

**The emergent behavior of hotspot distribution with respect to proximity to water bodies.**

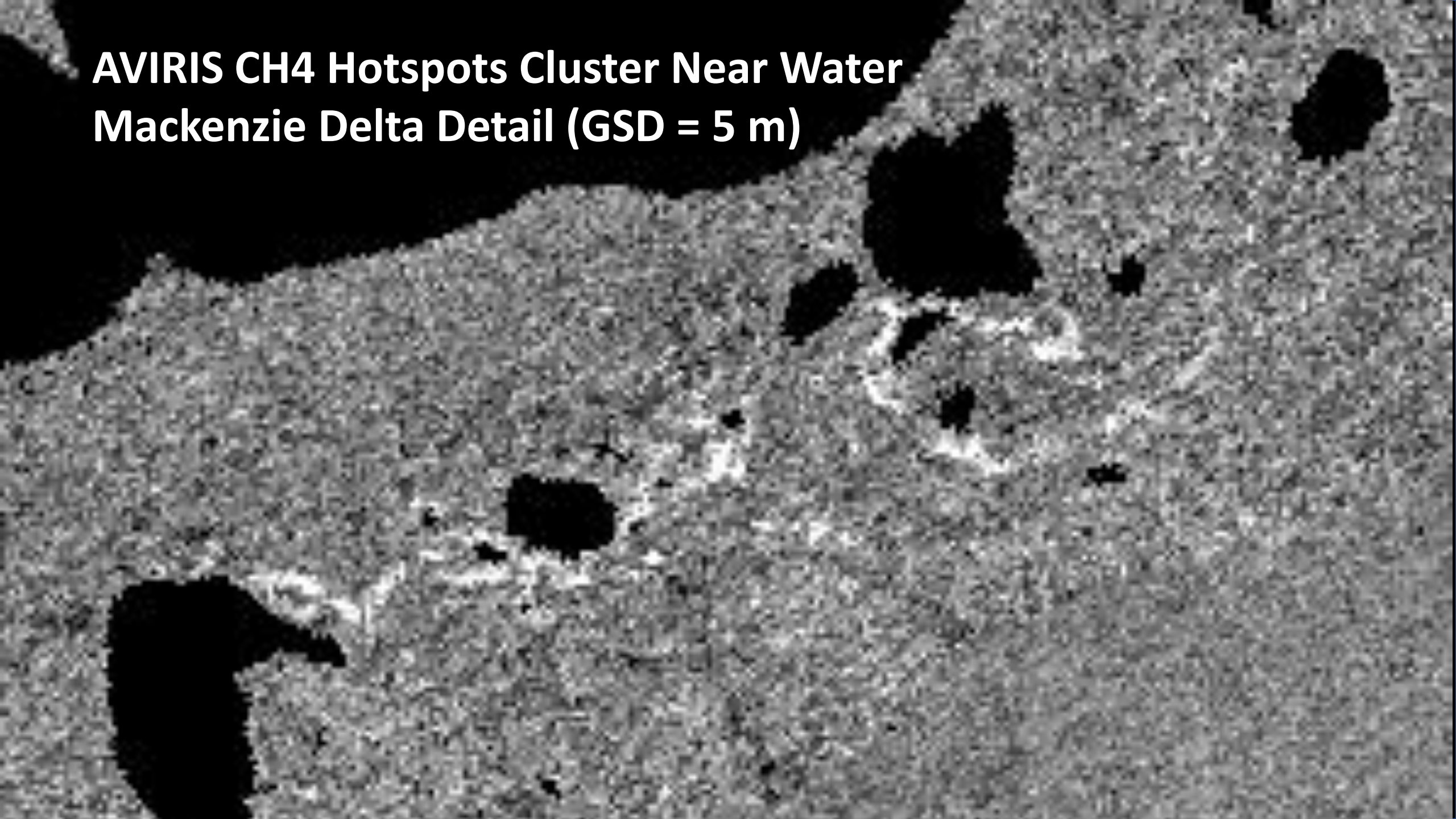


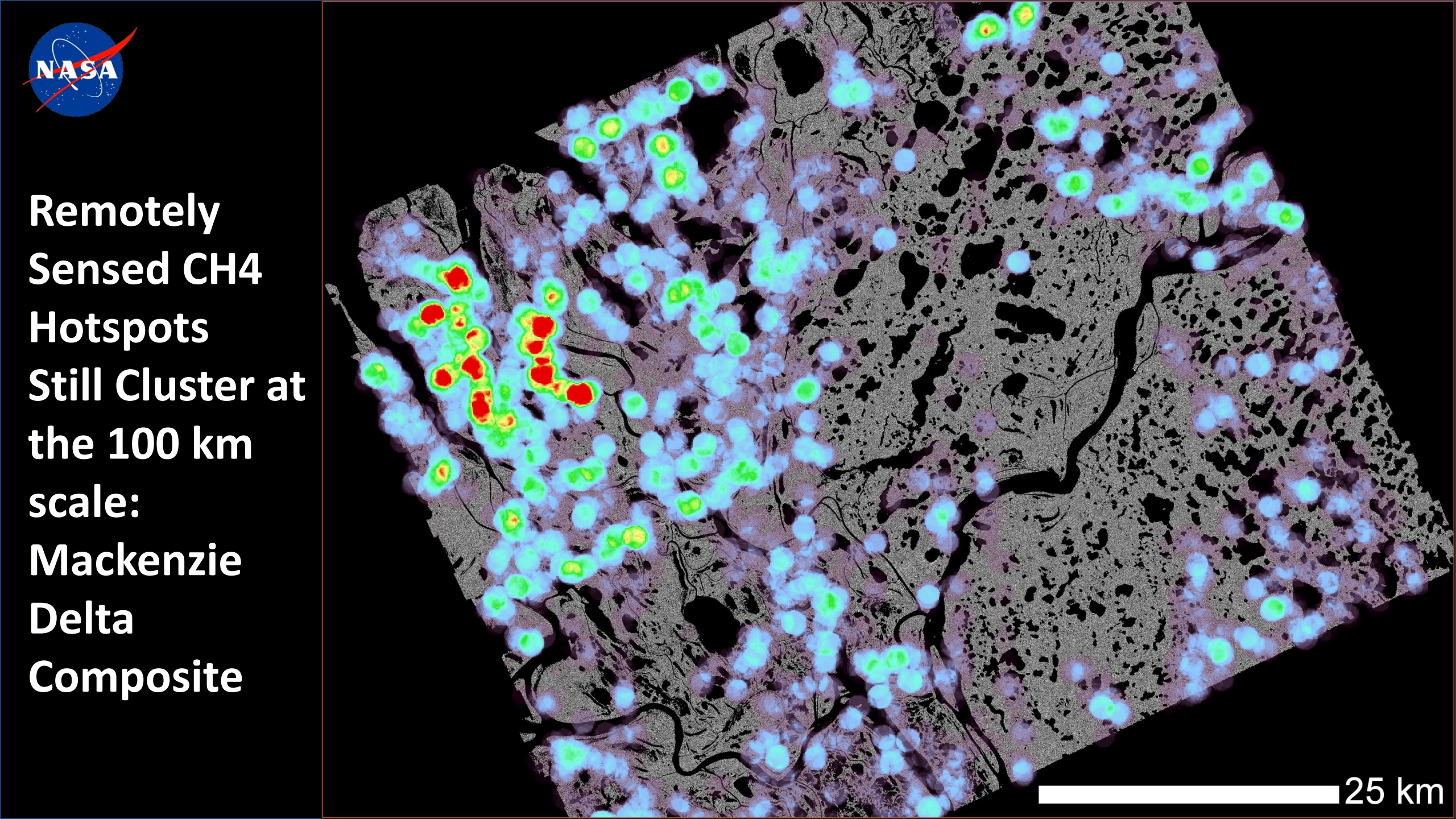




*Elder et al. 2020*

**Significance:** Fine-scale distance thresholds from water have a significant impact on the occurrence of hotspots –quantified valuable metrics for improving the accuracy of regional emissions upscaling, model validation, and emission forecasting.

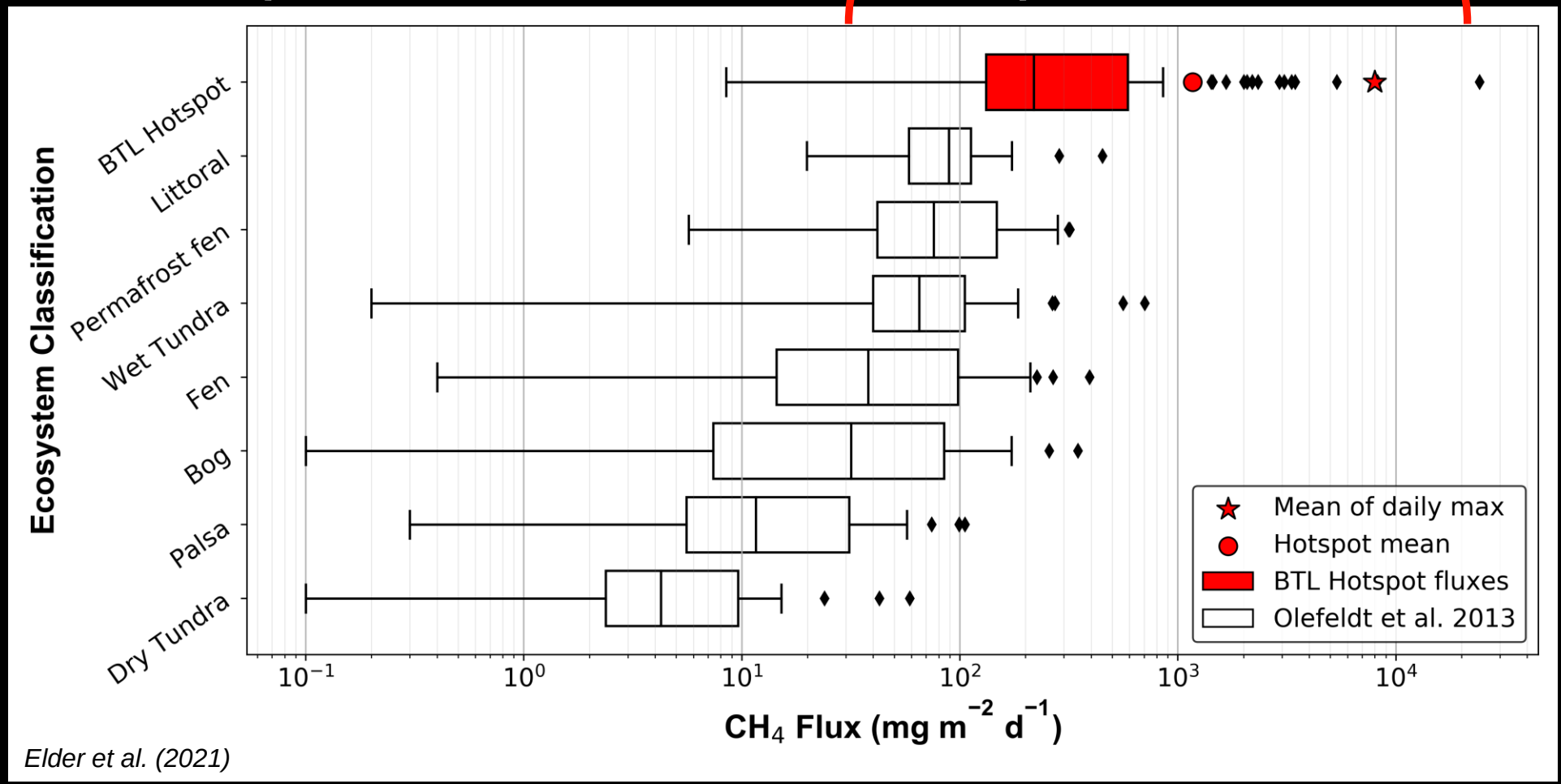

AVIRIS CH4 Hotspots Cluster Near Water
Mackenzie Delta Detail (GSD = 5 m)


Remotely Sensed CH4 Hotspots Still Cluster at the 100 km scale: Mackenzie Delta Composite
25 km

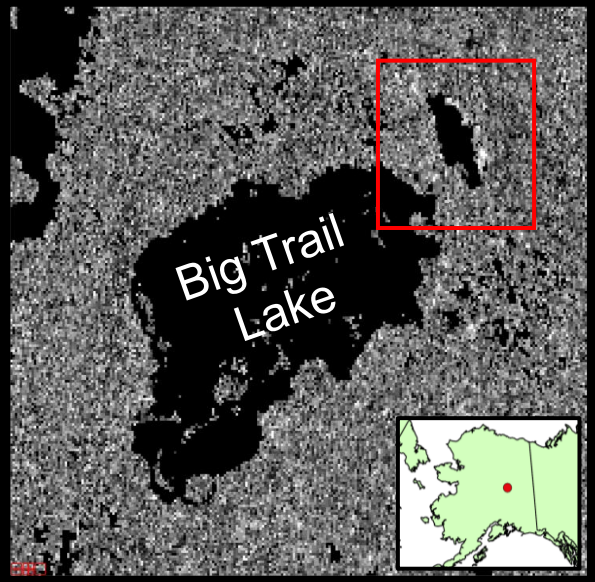
# Ground validation observations from AVIRIS-NG-detected hotspots confirm **extreme** diffusive emissions

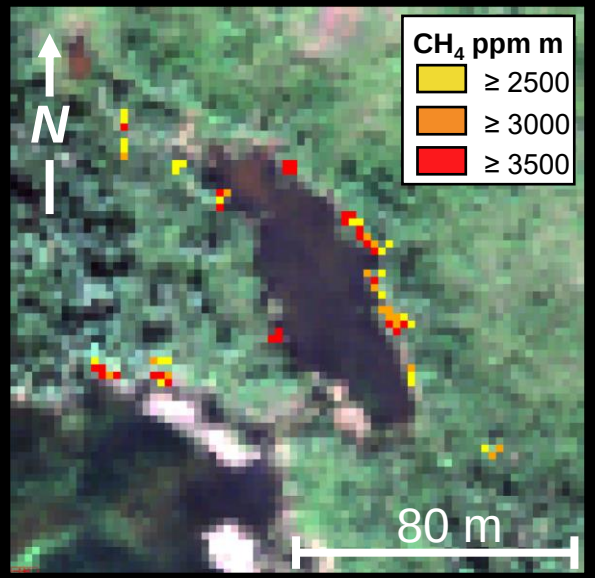
**Pan-Arctic flux database by ecosystem type (Olefeldt et al. 2013)**

**Observed hotspot fluxes**



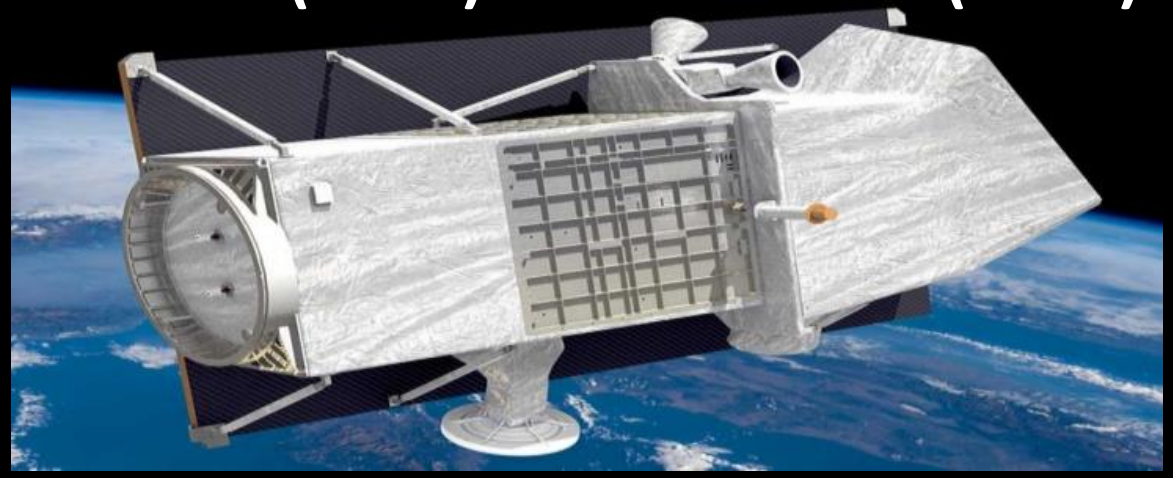

*Elder et al. (2021)*



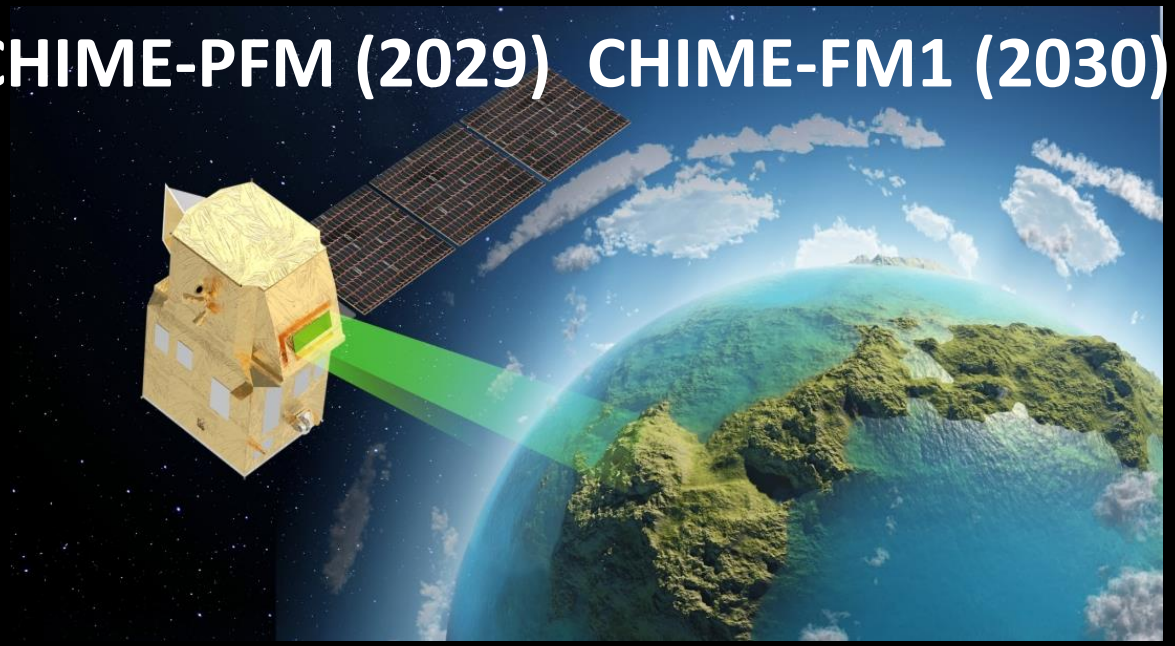
# Pan-Arctic CH4 Hotspot Monitoring Enabled by VSWIR Hyperspectral Imagers

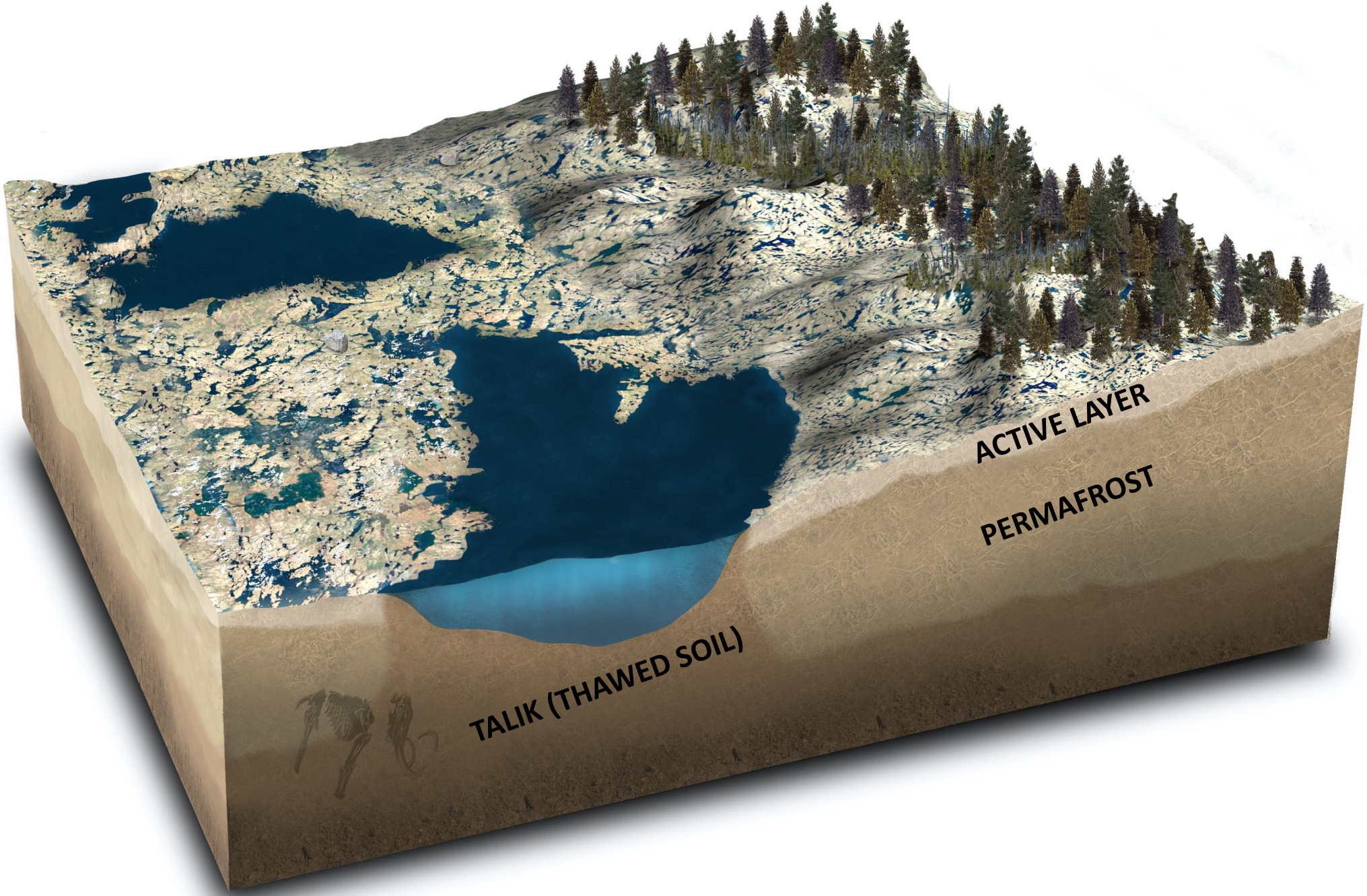
**PRISMA (2019)** **PRISMA-2G (2025)**



**SBG (2028)**

**CHIME-PFM (2029)** **CHIME-FM1 (2030)**



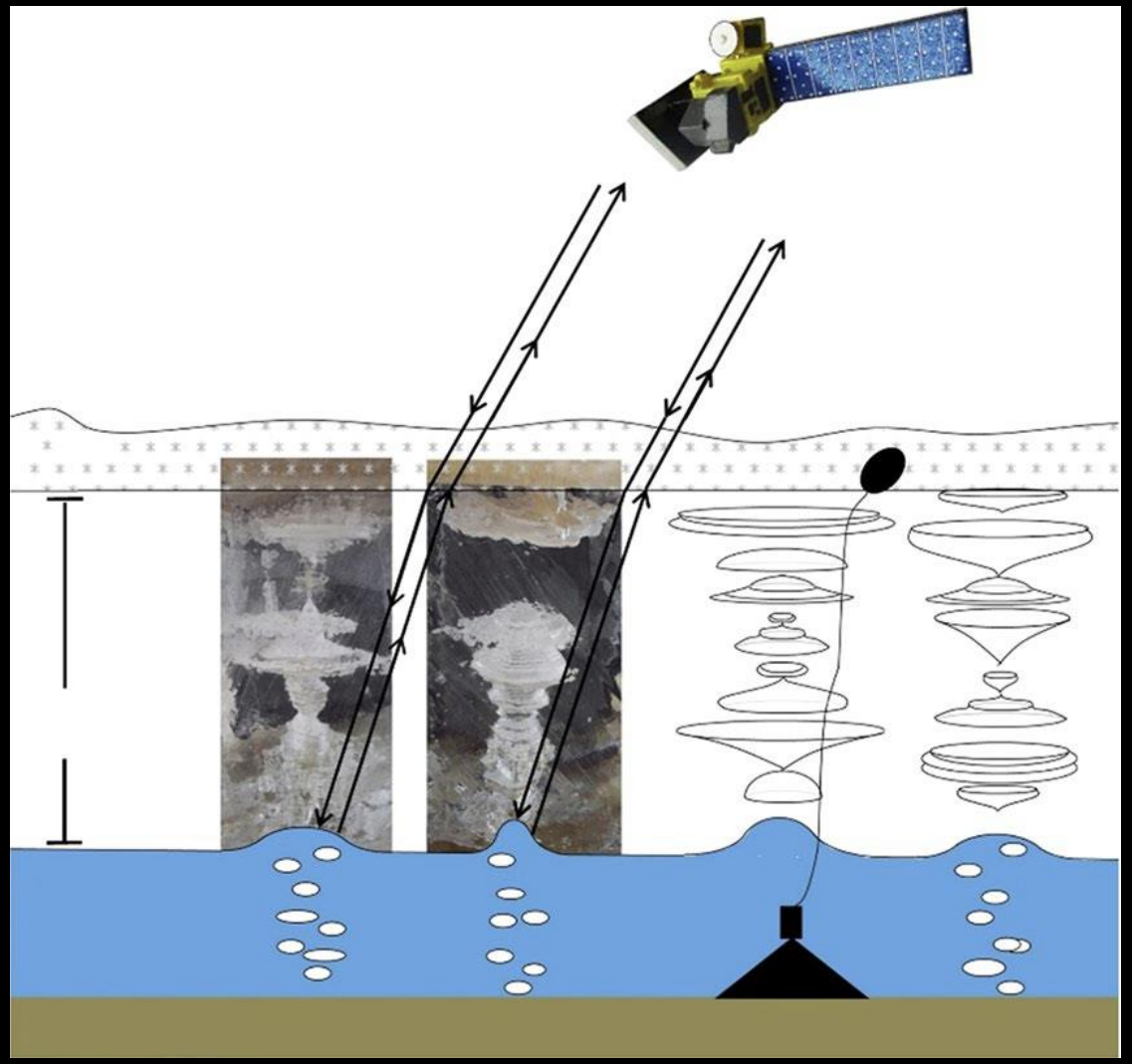


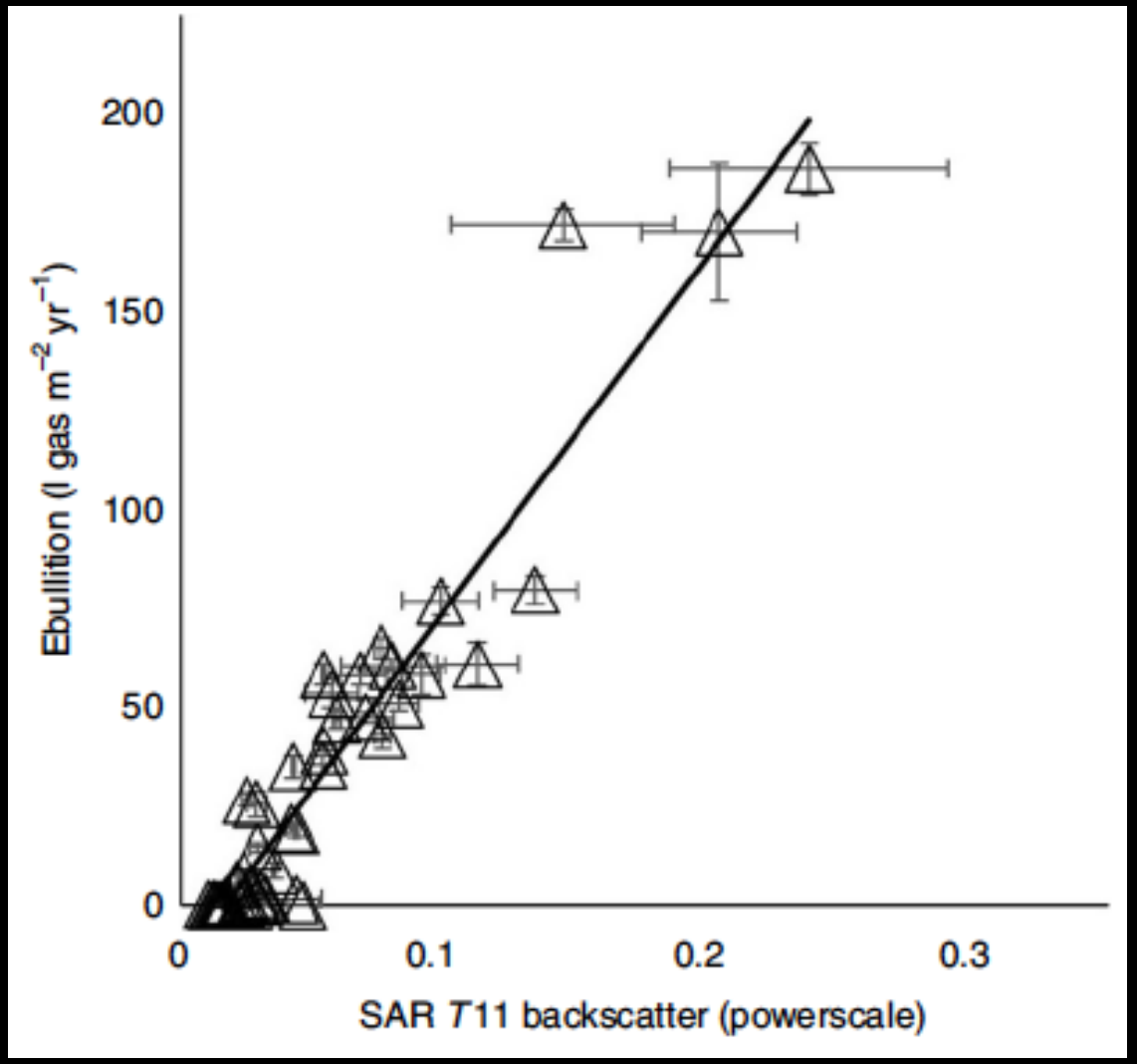

*Miner et al., Nature Rev Earth Environ (2021)*

Video Credit: Jonathon Newton, Washington Post

Photo Credit: Kristina Makeeva

# Using Space-based Synthetic Aperture Radar (SAR) to Quantify Northern Lake CH4 Emissions






*Engram et al., Nature Climate Change (2020)*

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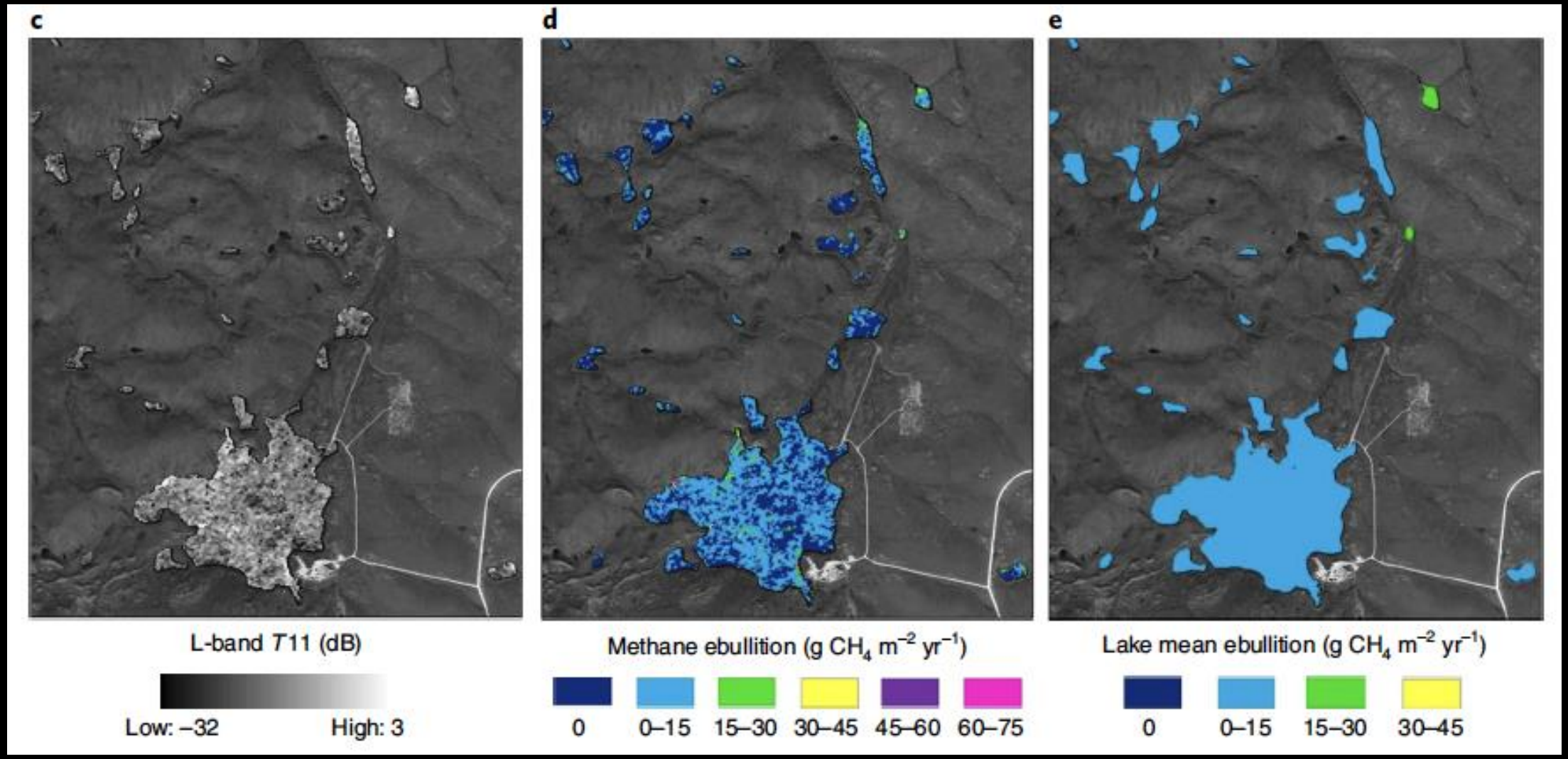


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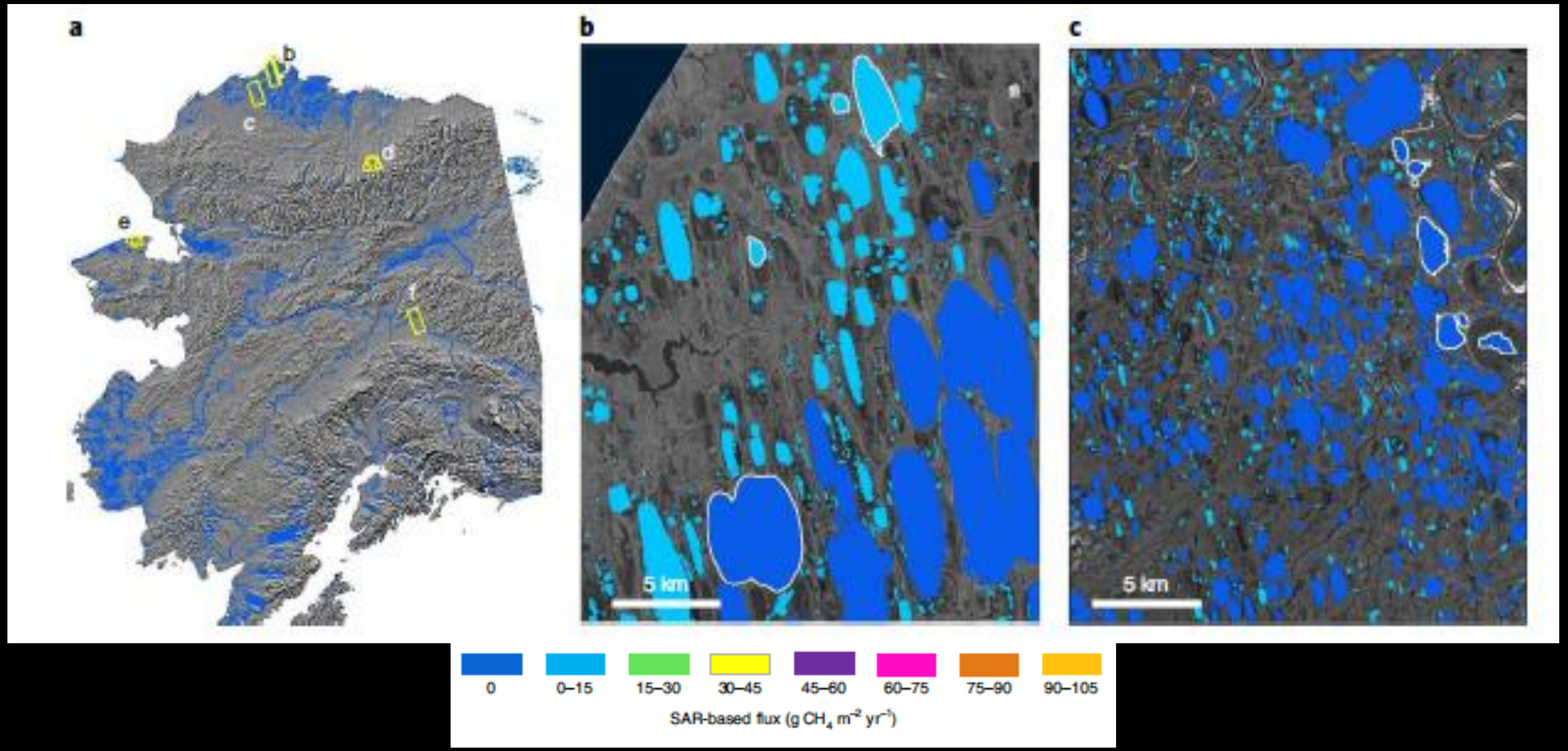



*Engram et al., Nature Climate Change (2020)*

# Monitoring Arctic Lake CH4 Emissions With Next Generation L-band PolInSAR Satellites

## NISAR

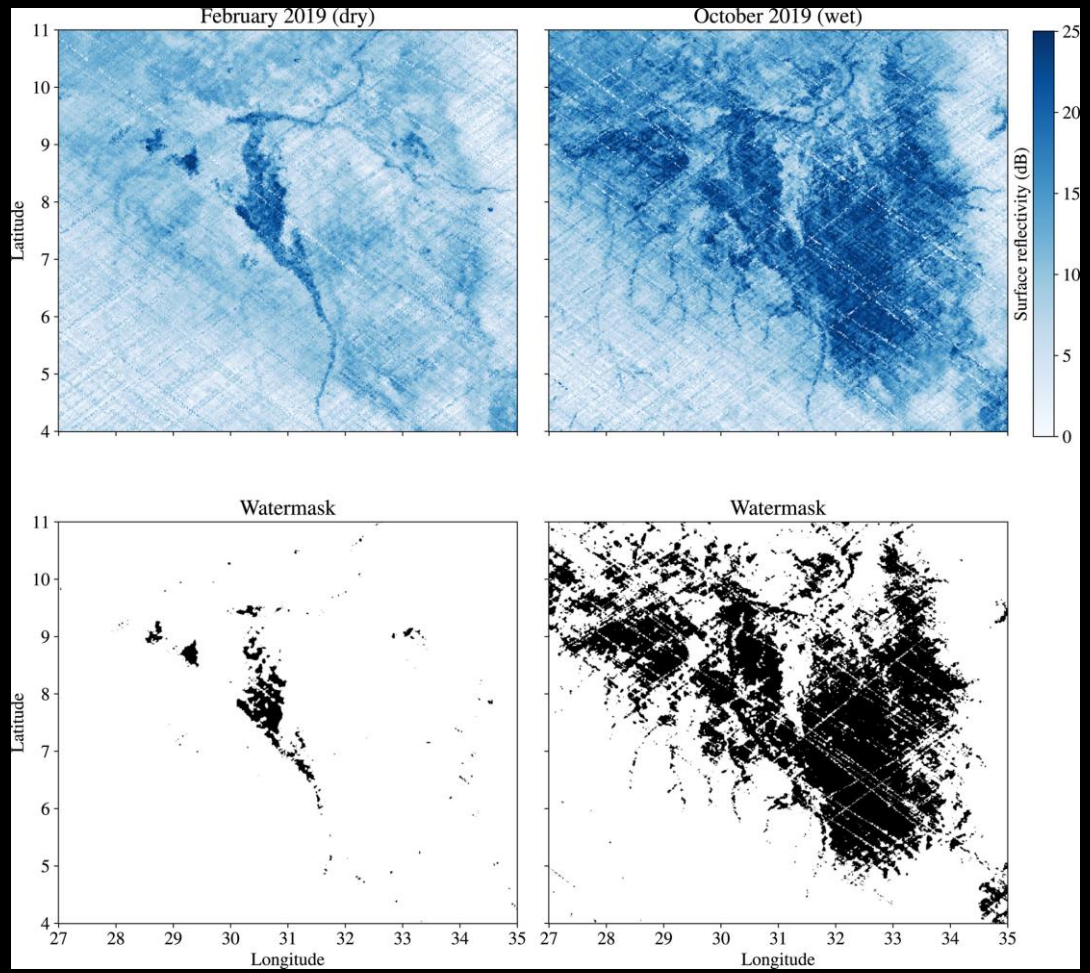
## ROSE-L

# PolInSAR Mapping of Thermokarst, Disturbance & ALT

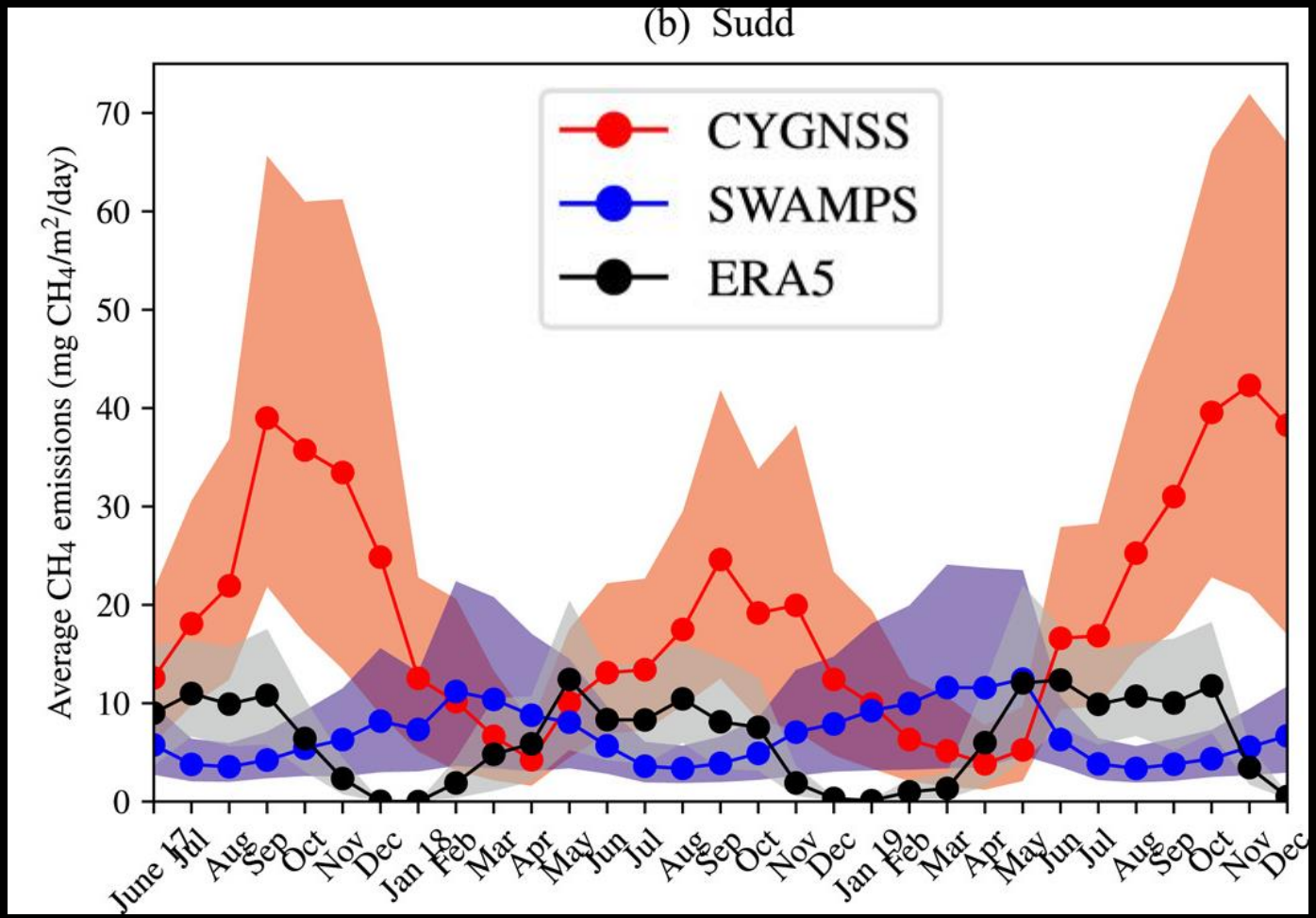

FM2 mega slump

# Potential for Dynamic Monitoring of Arctic Wetlands With GNSS Reflections (L-band)

## CYGNSS Wetlands

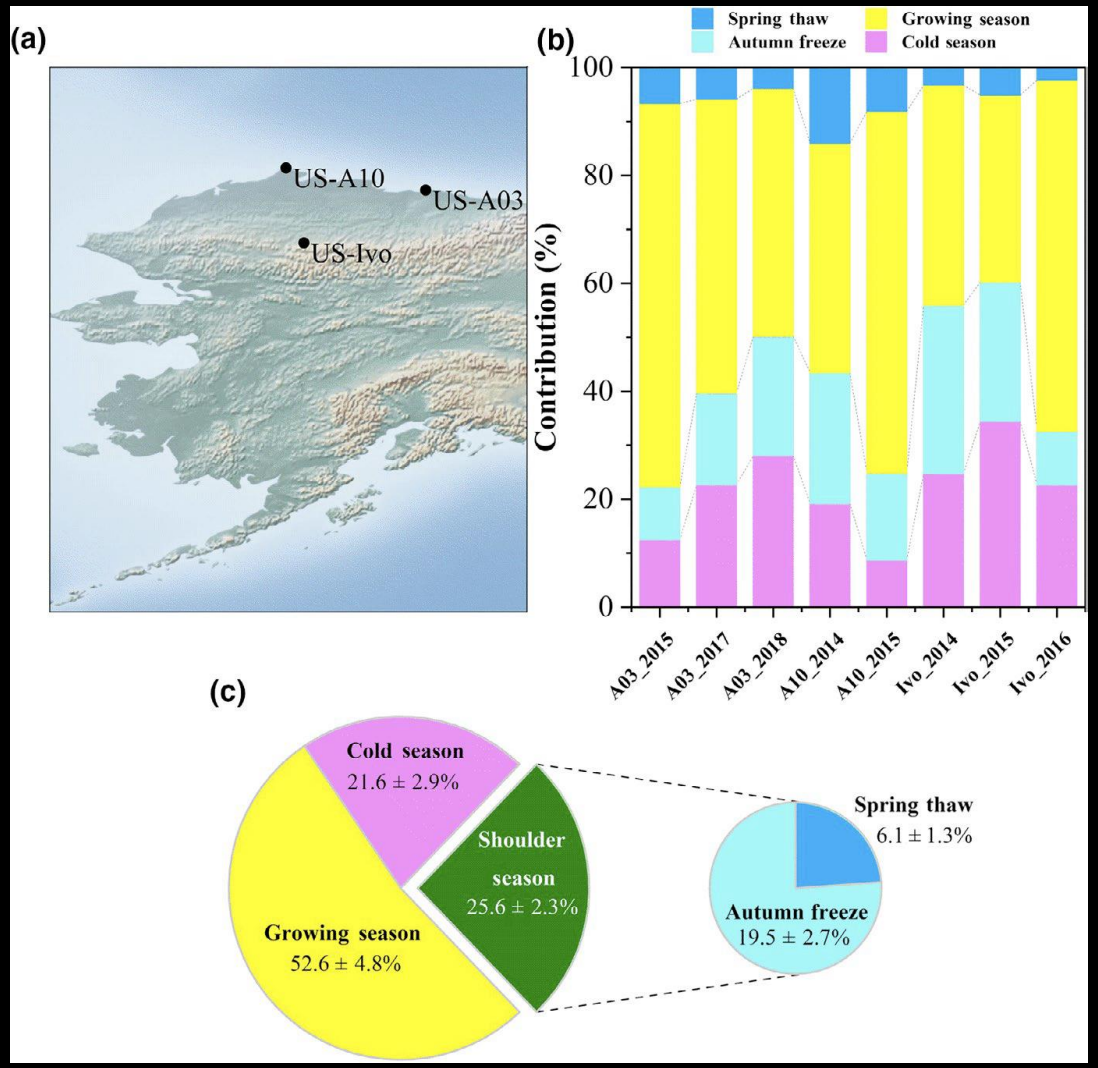



## CYGNSS-Driven CH4 Estimates

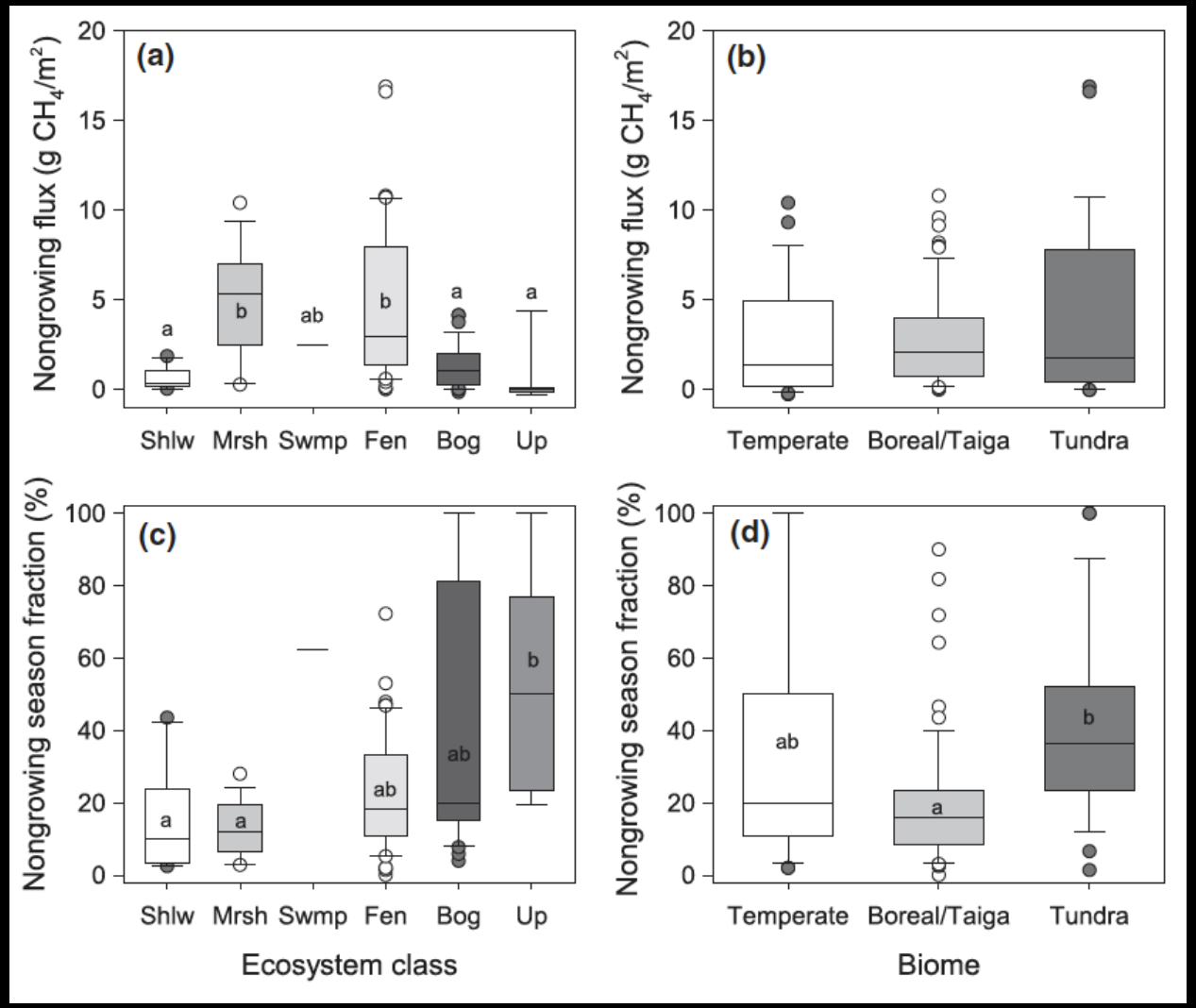



*Gerlein-Safdi et al., Global Biogeochem Cyc (2021)*

# Non-Growing Season Arctic CH4 Fluxes Account for Approximately 50% of Annual Emissions

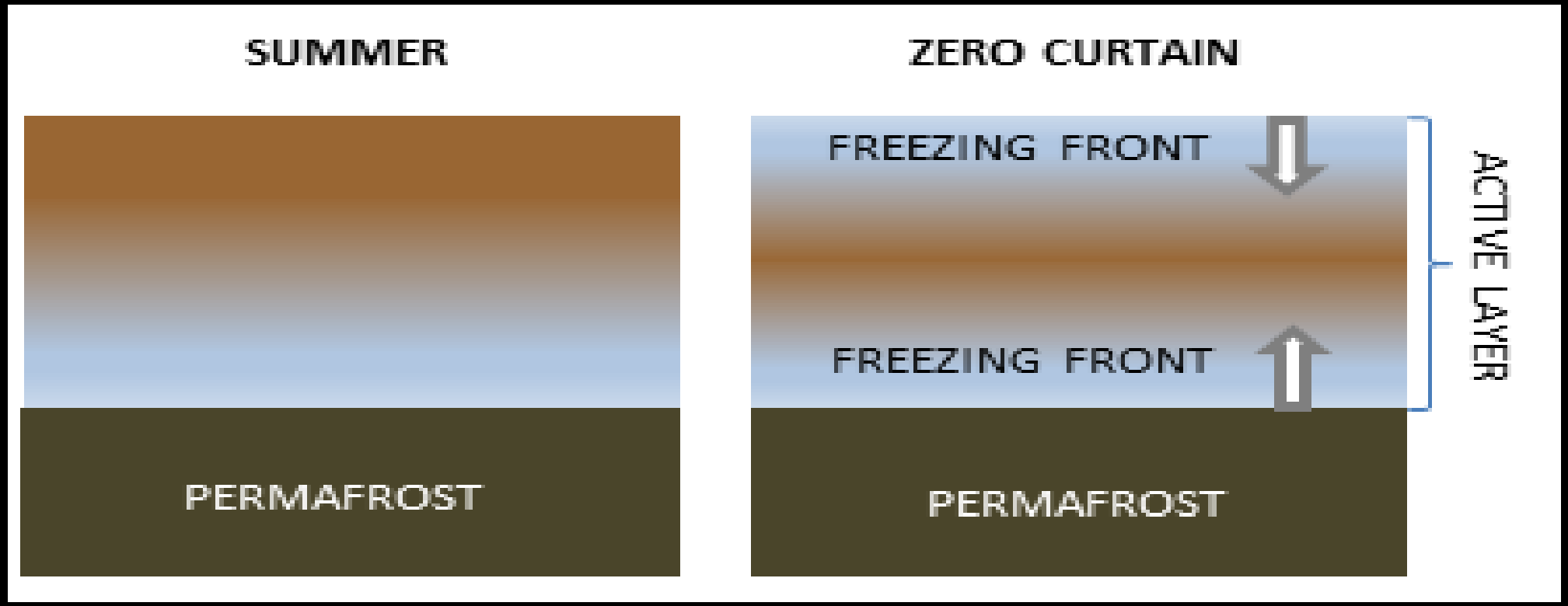



*Bao et al., Global Change Biol (2020)*




*Treat et al., Global Change Biol (2018)*

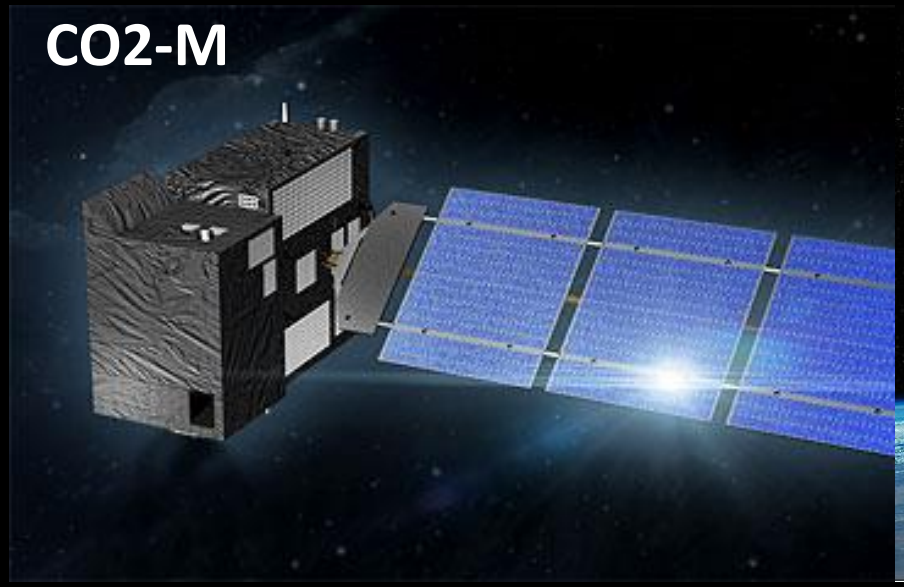
# Map Pan-Arctic Zero Curtain Duration and Extent With Satellite SAR




*Zona et al., PNAS (2016)*

- Microbial metabolism continues into the early cold season – “zero curtain period” – as long as liquid water is available
- North Slope zero curtain period now extends into December and is longer than the thaw season
- Soil temperature is the driving environmental control in cold season respiration

# Satellite Monitoring of Arctic CH4 Will Continue Into the 2030s









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