Welcome & Introduction
PV and Energy Security in the Greater Arctic Region

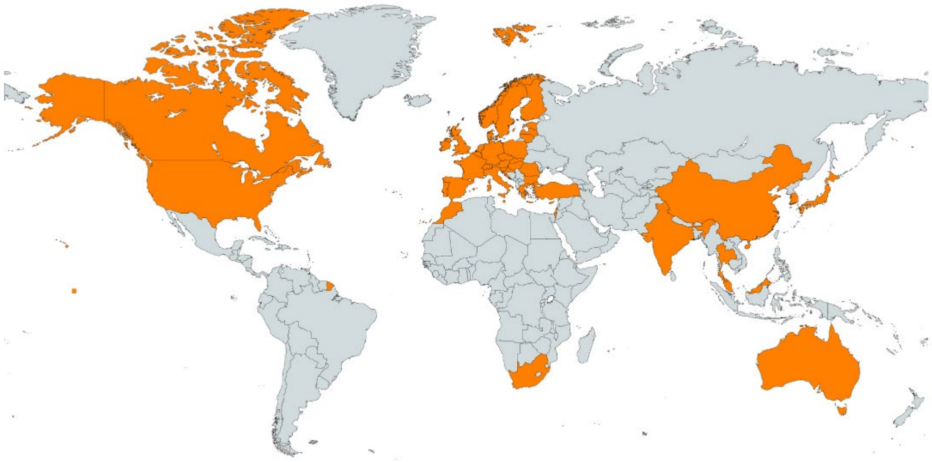
Ulrike Jahn, Task Manager of IEA PVPS Task 13

IEA PVPS in a nutshell

- One of 38 currently active Technology Collaboration Programmes within the IEA
- 33 years old – established in 1993
- 28 countries plus the European Commission and 2 Sponsors
- 9 active Tasks and 1 Action Group
- 27 reports published and 20 events organized in the past year
- ~400 participants across ExCo and all Tasks

PVPS

Our members



- Australia
- Austria
- Belgium
- Canada
- China
- Denmark
- European Union
- Finland
- France
- Germany
- India
- Israel
- Italy
- Japan
- Korea
- Lithuania
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- Morocco
- Norway
- Portugal
- SERIS
- SolarPower Europe
- South Africa
- Spain
- Sweden
- Switzerland
- Thailand
- The Netherlands
- Türkiye
- United Kingdom
- United States of America

Task 13 Collaboration - History and Presence

Task 13: Reliability and Performance of Photovoltaic Systems

Task 13: 2010-2014

+ Performance and reliability of components
+ Testing and standards

Task 13: 2014-2017

+ Economical aspects and business models
+ Yield prediction & uncertainties
+ Failure detection and statistics

Task 13: 2018-2021

+ New module and system designs
+ Field testing
+ O&M practice
+ Risk assessment & mitigation

Task 13: 2022-2025

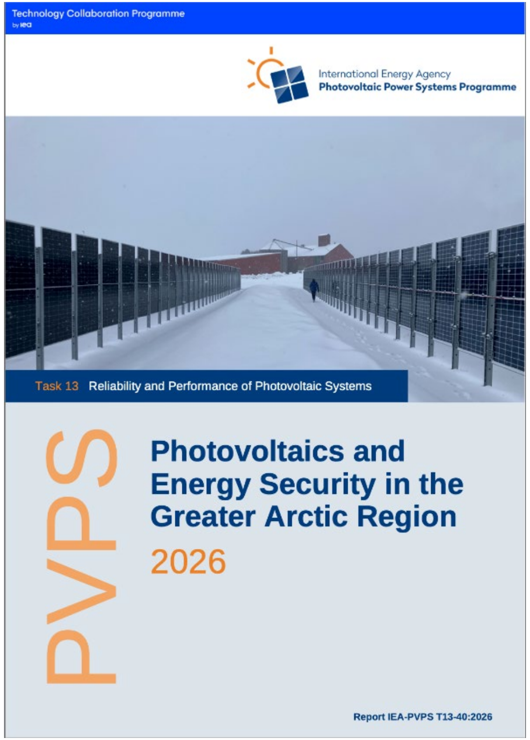
+ New materials & applications (IPV)
+ Digitalization
+ Climate/environment specific design/testing
+ Techno-Economic key performance indicators
+ Second Life PV
+ PV & storage

Task 13: 2026-2029

- PV module structures
- Digitalization and AI
- PV Applications
- PV Enabler

Why are we doing this Webinar?

- The **TASK13** analyses Performance, Operation and Reliability of PV Systems in different climates
- Recent report T13-40-2026 ➔
  shows that PV can make a meaningful contribution to Arctic energy systems with climate-specific design.
- It requires high-quality solar resource and albedo data, improved modelling approaches for snow losses, careful geotechnical assessments in permafrost regions.
- It explores the unique **opportunities and challenges of deploying PV systems at high latitudes**.



J.S. Stein, et al., "Photovoltaics and Energy Security in the Greater Arctic Region," Report IEA-PVPS T13-40:2026, 2025. doi: 10.69766/JXHM9635.

Why PV in the Arctic? - Challenges

Why: ~17.2 million people live above 60°N (as of 2025) and many communities rely on expensive imported diesel fuel

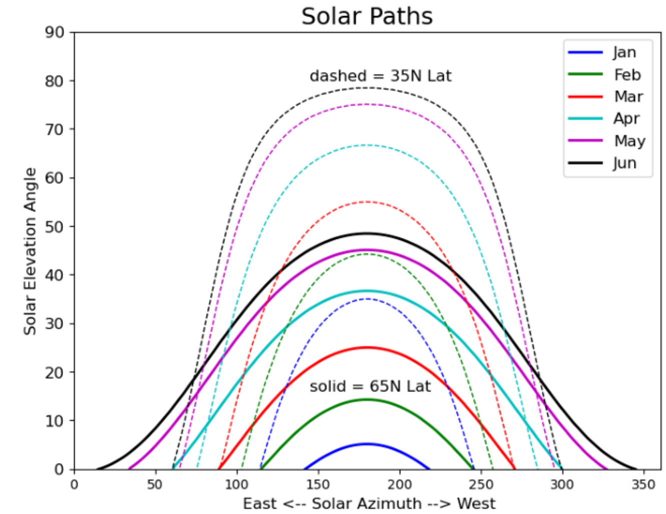
Challenges:

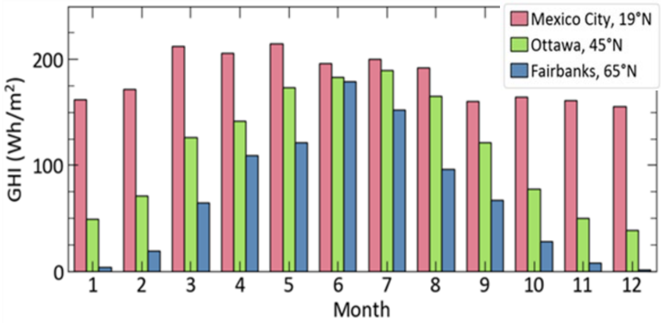
- Dark winters — months with no/minimal sunlight above Arctic Circle
- Heavy snow loads, high winds, extreme cold affect reliability
- Material property changes at low temps (e.g., EVA glass transition at -15°C)
- Remote locations: high shipping, installation, and O&M costs
- Isolated microgrids require significant energy storage

High Seasonality in Solar Resource

Low solar elevation angles at 65°N

Very wide azimuth range in summer





GHI, zero in winter

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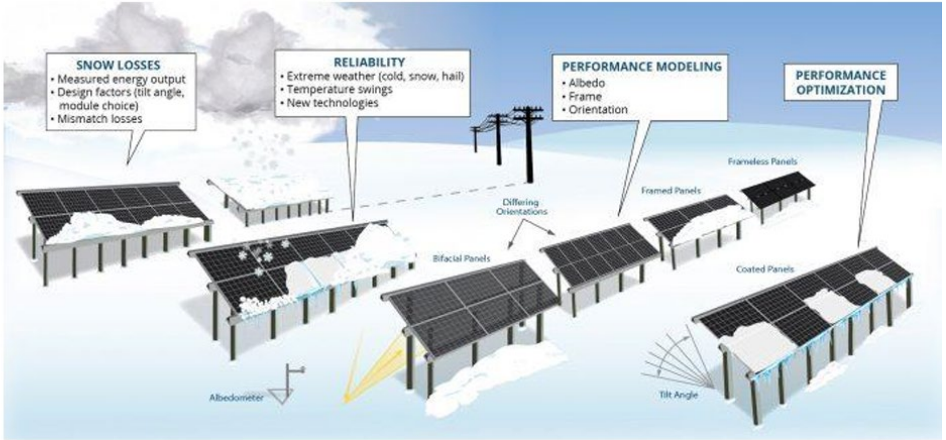
Best Practice: High-Latitude PV Deployments

Vertical rooftop arrays in Norway

Vertically oriented bifacial PV systems (typically oriented E-W) can capture light effectively in high-latitude regions where solar elevation angles are low, and solar azimuths have a large range.

Design consideration for SNOW \ ICE accumulation



Snow impact on PV performance and design aspects to keep in mind

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More information on IEA PVPS:

www.iea-pvps.org

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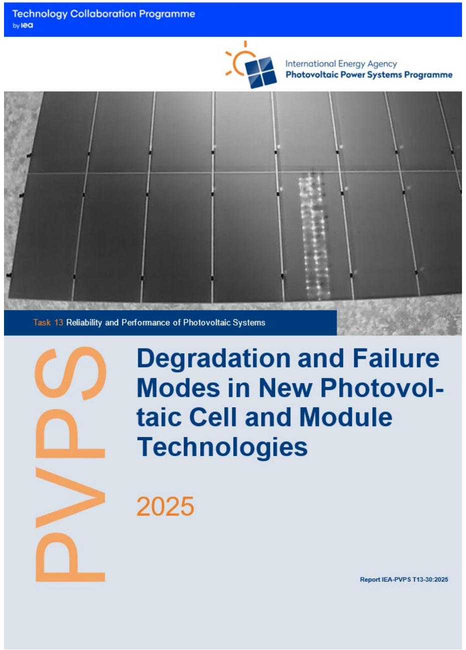
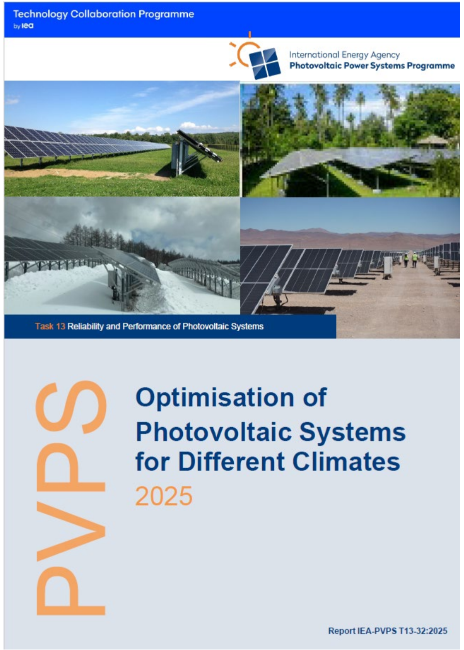




This report overviews currently known degradation modes and failures of PV module technologies and their mitigations.

The report explores strategies for enhancing the performance of PV systems in different climates.

Dr. Erin Tonita

Natural Resources Canada

Dr. Adam R. Jensen

Technical University of Denmark

Dr. Joshua S. Stein

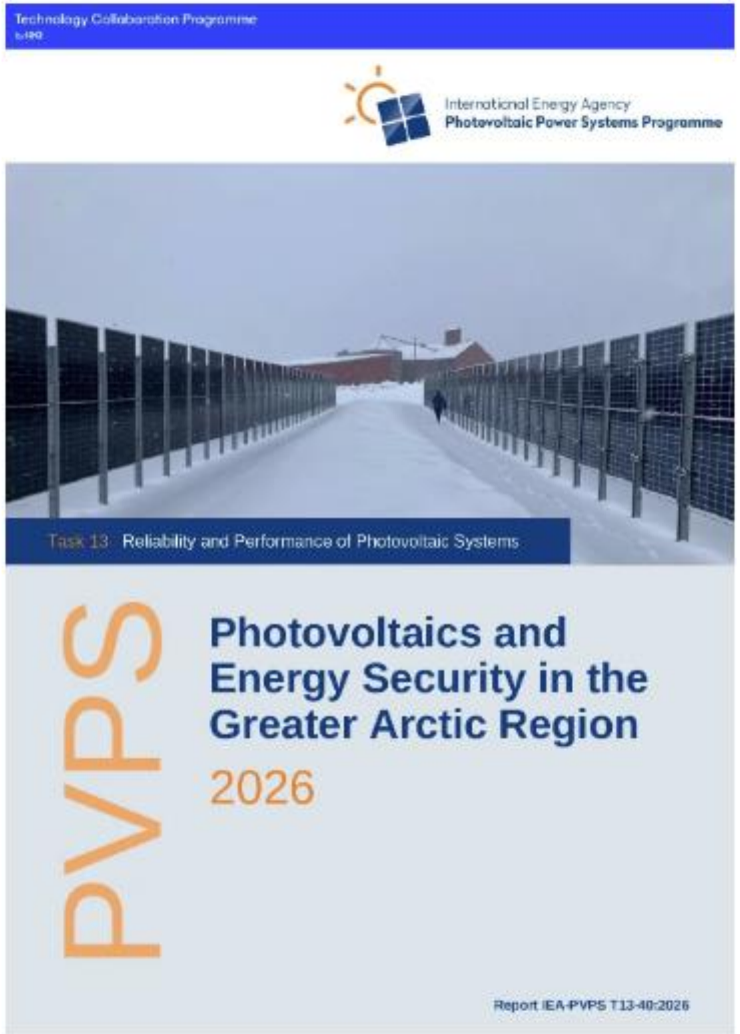
Sandia National Laboratories, USA

The Arctic Context for Solar Photovoltaics

Erin Tonita

IEA PVPS Task 13 Webinar

April 30, 2026



Report IEA-PVPS T13-40:2026, February 2026

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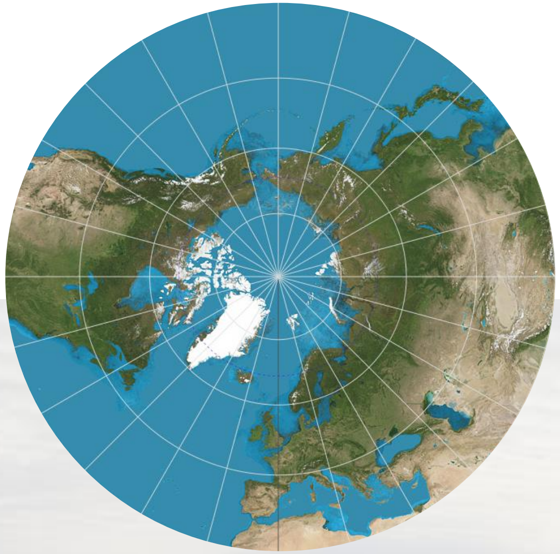
The Greater Arctic Region



- “The greater Arctic region/circumpolar north” = above **60°N** in our report
- Region contains **diverse climates & cultures**, while sharing distinct characteristics
  - Low population density
  - Extreme seasonality
  - Permafrost & snowfall
  - High exposure to climate change impacts
- **>17 million** people live above 60°N, across **~13%** of Earth’s surface

<u>Two electricity paradigms</u>

1. **Grid-connected** regions
   - → Nordic countries, parts of Russia
   - Historically use hydro, nuclear, wind

2. **Isolated microgrid** communities
   - → Alaska, northern Canada, Greenland, parts of Russia
   - Diesel-dominated energy use

Energy Challenges in High Latitudes

- Energy in the Arctic is about **security & resilience**, not only decarbonization
- Many regions have heavy reliance on imported fossil fuels
  - ↳ High & volatile electricity costs

In many Arctic communities
- Electricity prices can be **3-10×** higher
- Challenging & limited fuel transportation
- Energy supply critically linked to health services, safety

Image source: The Arctic Deeply (2017)

- **Arctic warming 2-4× faster than global average**

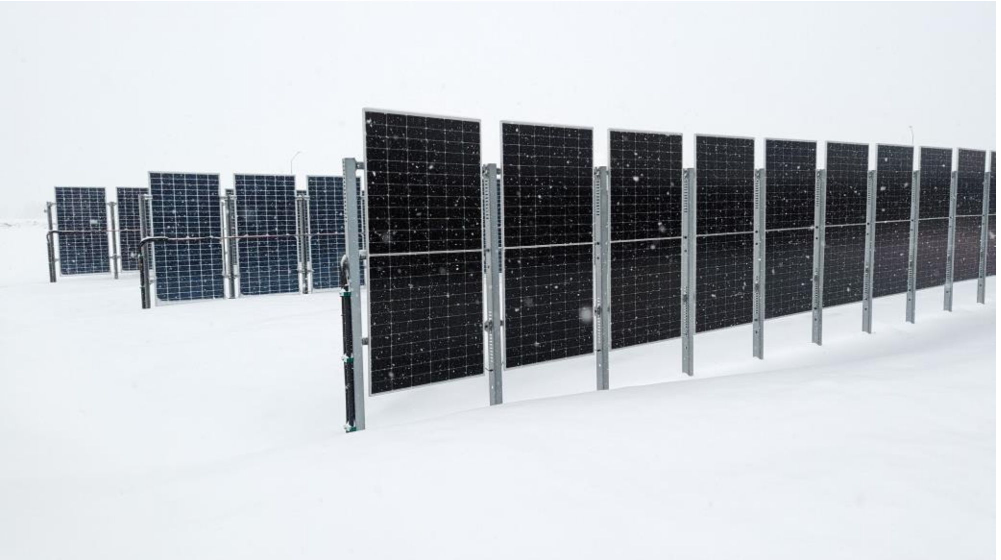
Image source: Arctic Council, Old Crow (2020)

→ Region of high energy innovation

→ Arctic communities are leading as examples of high PV-penetration grids (20-25%)

→ Community-driven renewable energy projects can be used as a driver for indigenous self-determination

Why Solar PV?



- PV costs have dropped dramatically
- PV can largely **displace diesel** during summer months
  - Long summer days = high solar potential
- Reduces fuel shipments and spill risk
- Diversifies electricity mix
- PV is **modular & scalable** for community or regional needs

Arctic countries are increasingly deploying solar PV

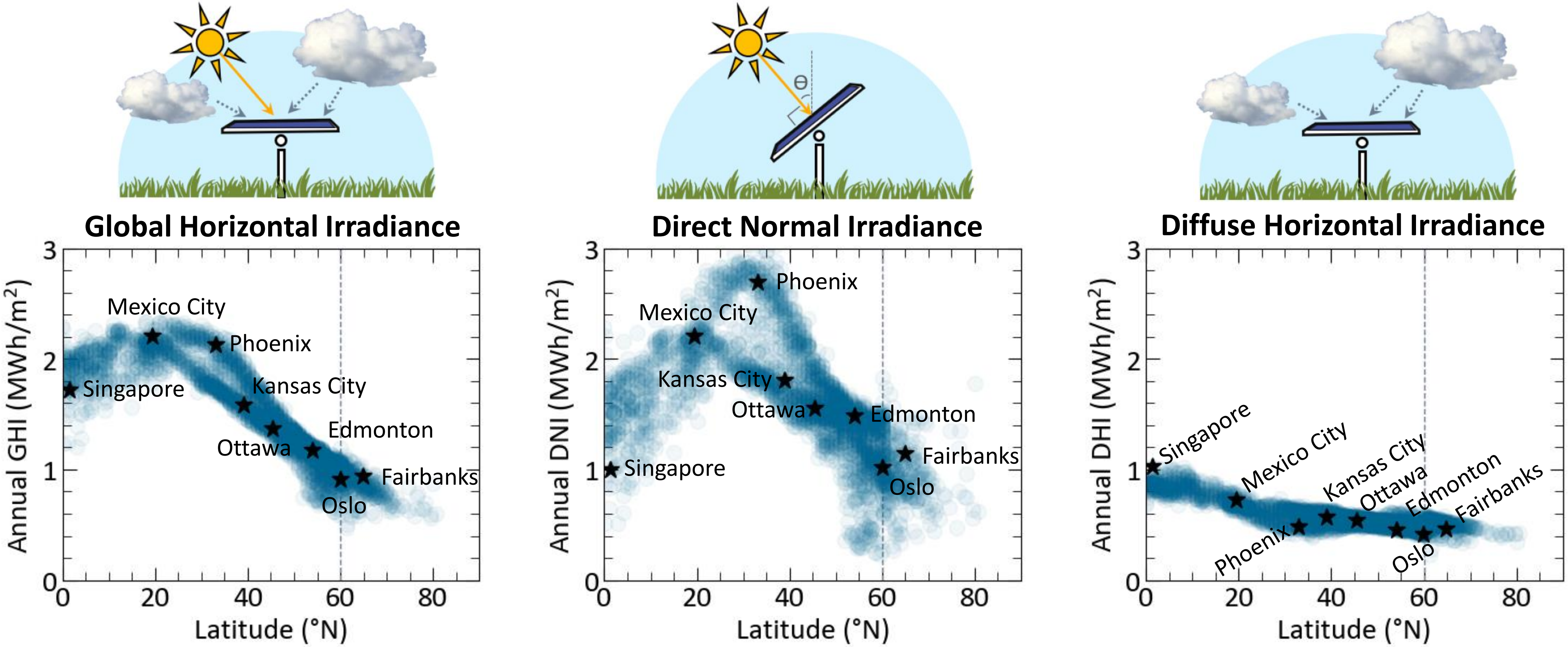
- Community-scale PV growing rapidly in Canada & Alaska
- Utility-scale PV becoming viable in Nordic countries
- Annual growth rates as high as **50-150%** observed in some Arctic regions

PV projects can be vehicles for:

- Indigenous energy sovereignty
- Local job creation
- Reduced exposure to fuel markets

Annual Solar Irradiance Decreases with Latitude

- Beyond the tropics there is a clear decrease in annual solar insolation with latitude

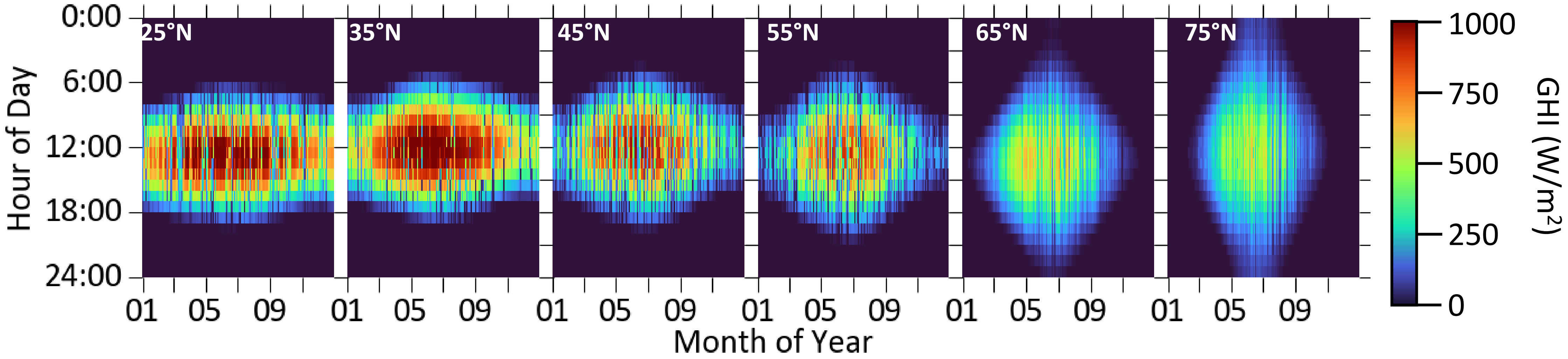


Data from National Solar Radiation Database (NSRDB) v3.2.2 <60°N; Data from PVGIS 5.2 >60°N

- Two clusters represent different climates (e.g. dry Western US and humid Easter US)

Midnight Sun & Polar Night

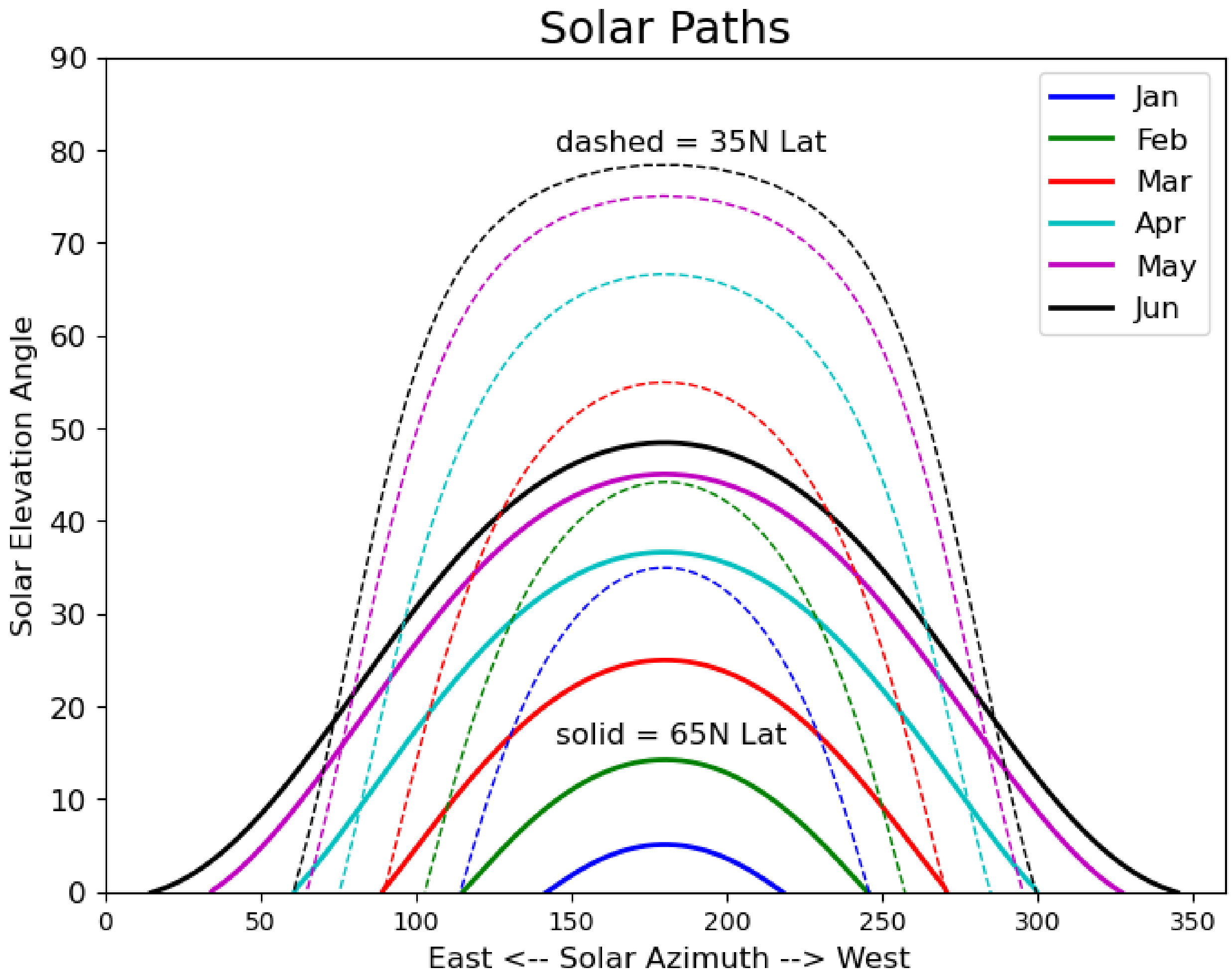
- Arctic regions experience **extreme seasonality**
  ↳ Why storage, hybridization, and design choices matter
- Above the Arctic circle: no sunlight at winter solstice, 24 hours of sunlight at summer solstice



Low Sun Elevation & Wide Azimuths

- Low solar elevation angles
- Very wide azimuth range in summer
- Sun often *behind* south-facing arrays in summer

→ Motivates vertical, bifacial, and east-west facing designs

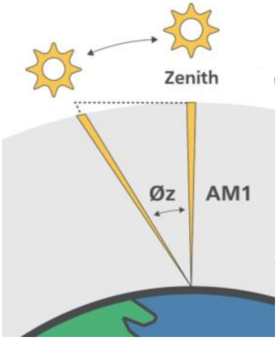


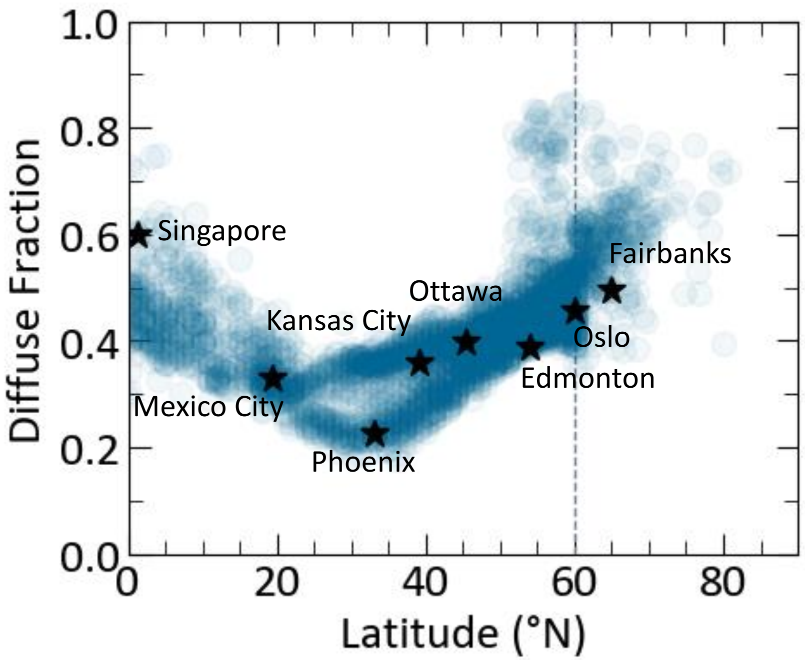
Higher Diffuse Fraction & Air Mass

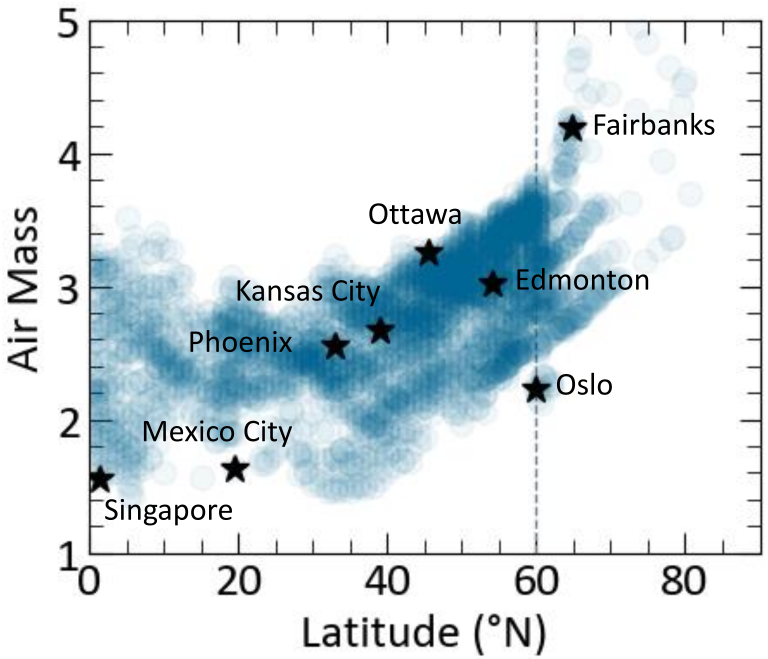
- Diffuse fraction increases at high latitudes, indicative of increased cloud cover
- Lower solar elevation leads to higher air mass and red-shift
- Higher air mass can boost silicon PV cell efficiency
- PV performance often differs from standard rated assumptions
- Arctic PV is not just about less sun → it is *different* sun

$$\text{Diffuse fraction} = \frac{\text{Diffuse horizontal irradiance}}{\text{Global horizontal irradiance}}$$

$$\text{Air mass} = \frac{1}{\cos \Theta_Z}$$

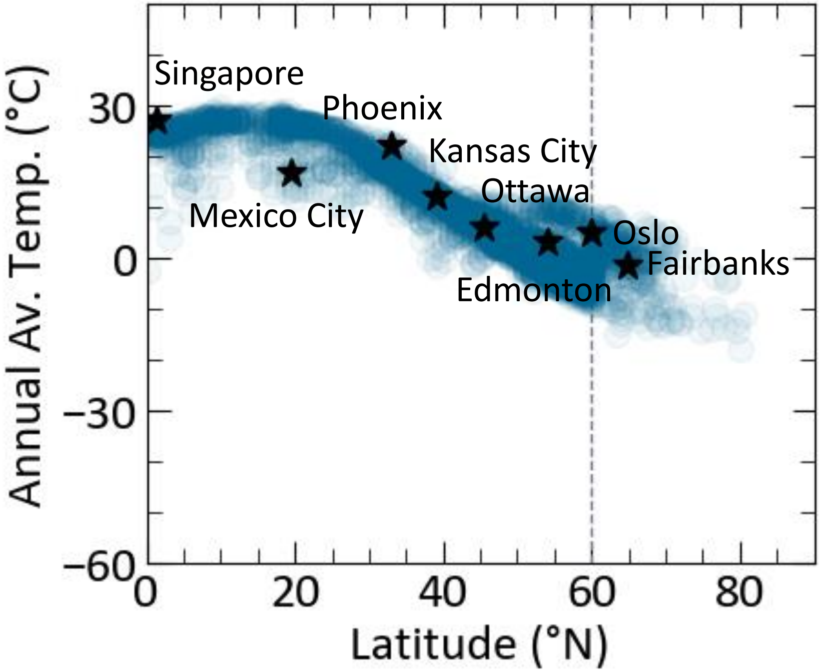


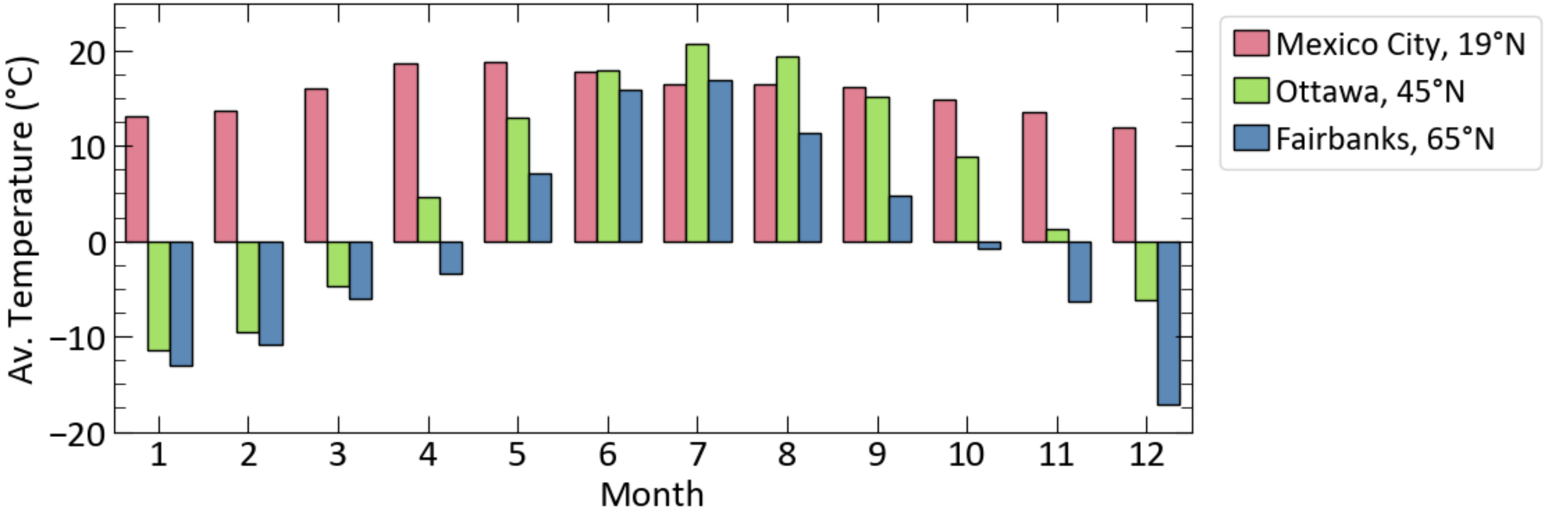




Ambient Temperature

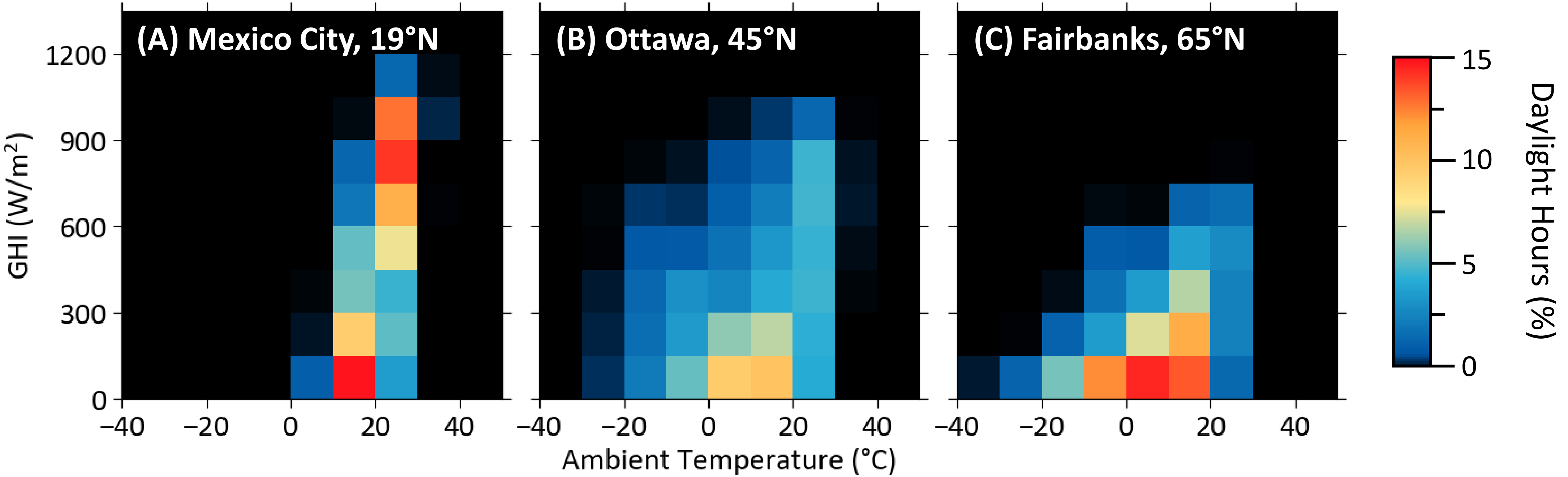
- Arctic temperatures are consistently lower year round
- Ex) Monthly average temperature in Fairbanks (65°N): -20°C to +15°C
- PV components must regularly survive -40°C





Ambient Temperature

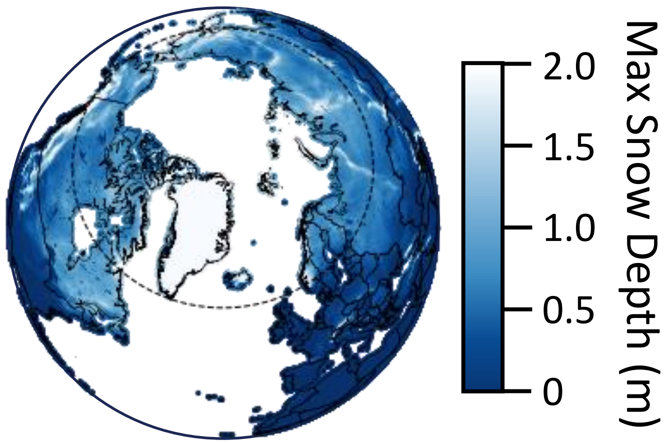
- Positive correlation between lower irradiance and cooler temperatures

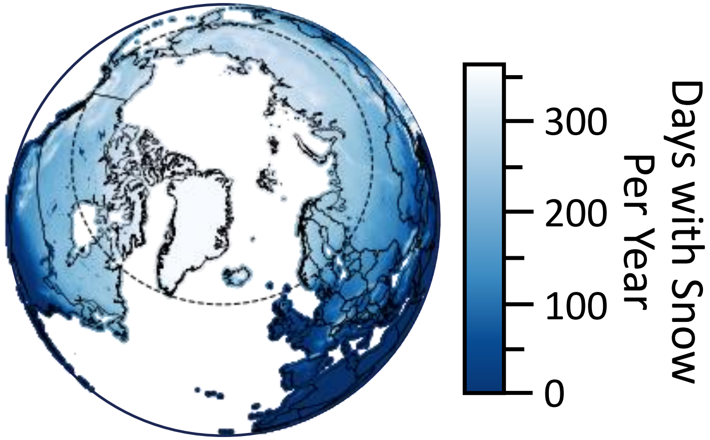


TMY data from National Solar Radiation Database (NSRDB) v3.2.2 (<60°N) and PVGIS 5.2 (>60°N)

- Lower temperature → higher PV cell efficiency and voltage & suppressed degradation mechanisms

Snow & Permafrost



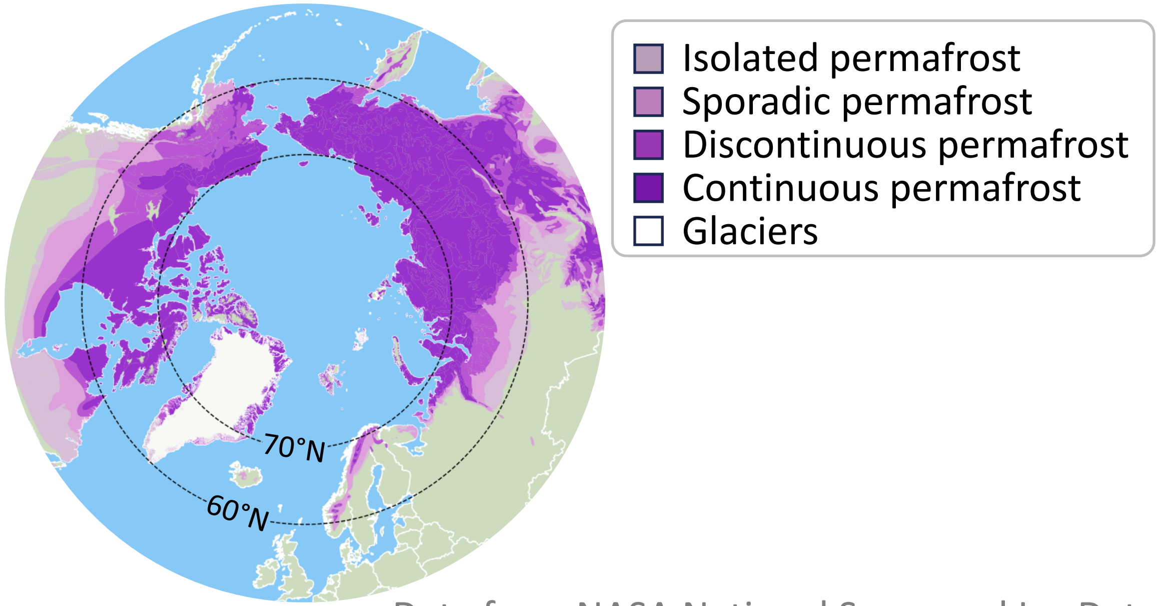


Data from ERA5-Land reanalysis dataset

- Snow can block light → PV losses
- Snow increases albedo → PV gains
- Many high latitude regions receive >200 days of snow per year
- Snow depth can be as high as 1-2 m

Permafrost =

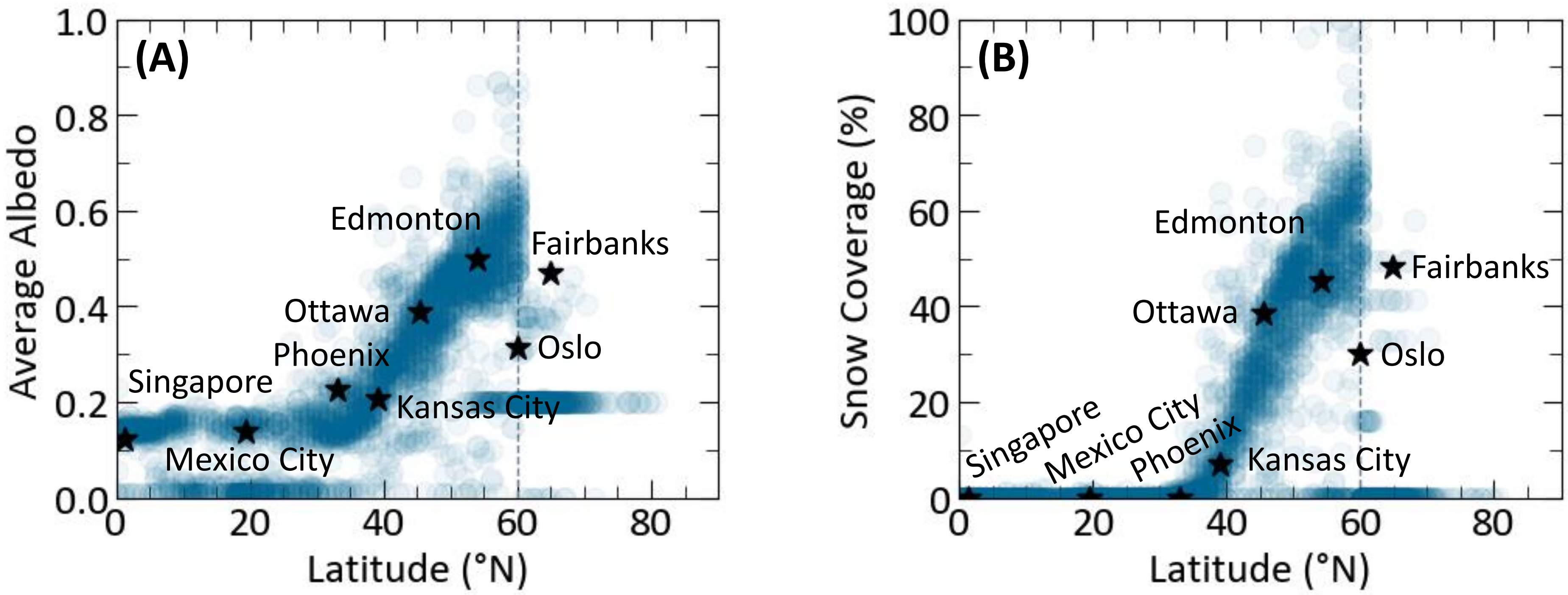
Ground soil that has remained frozen for at least two continuous years



Data from NASA National Snow and Ice Data Center

Snow Coverage & Albedo Data Challenges

- Snow coverage and albedo increase with latitude above ~35°N
- Percent of year with snow cover can be >60%



TMY data from National Solar Radiation Database (NSRDB) v3.2.2 (<60°N) and PVGIS 5.2 (>60°N)

- Weather datasets used in PV models can contain data artifacts and inaccurate assumptions for northern regions
- Albedo=0.2 as constant default in many cases

Key Takeaways

- PV is being rapidly adopted in Arctic regions
- Extreme seasonality defines PV production
- Key weather conditions: lower irradiance, unique solar paths, cooler temperatures, & snow

→ **Arctic PV requires context-aware design**

Thank you!
Contact:
Erin.Tonita@nrcan-rncan.gc.ca

100 kW vertical bifacial PV pilot plant near Luleå, Sweden constructed by the Sunna Group

136 kW solar PV array in Colville Lake, Canada operated by the Northwest Territories Power Corporation

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Solar irradiance data in the Arctic

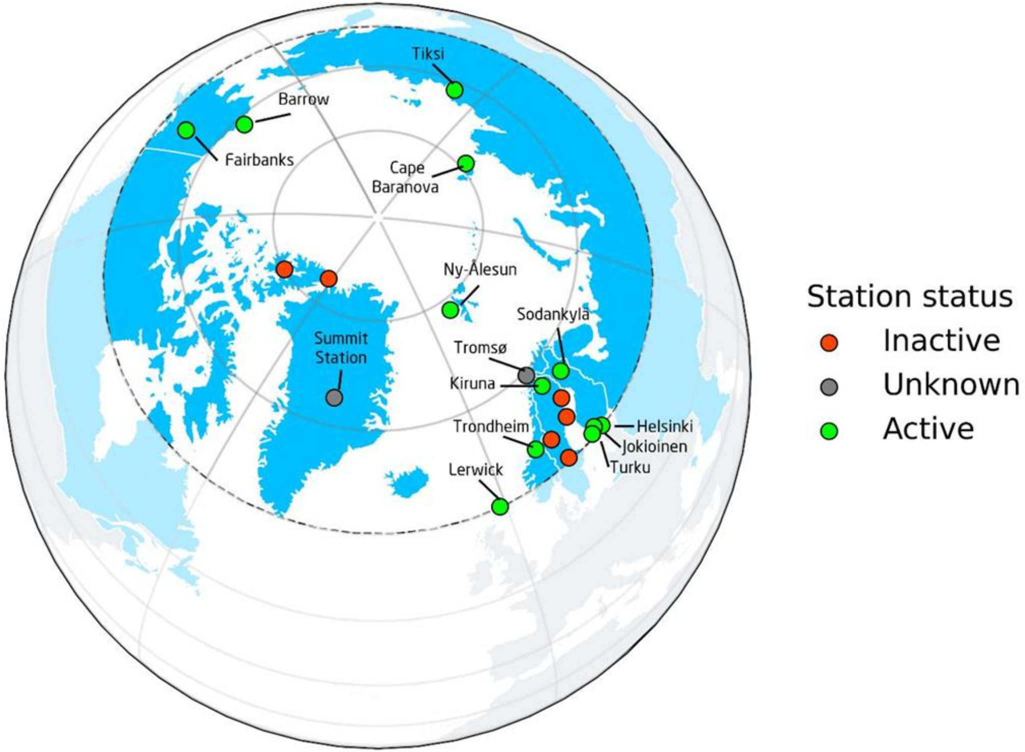
Adam R. Jensen

Task 13 Webinar: PV in the greater Arctic region

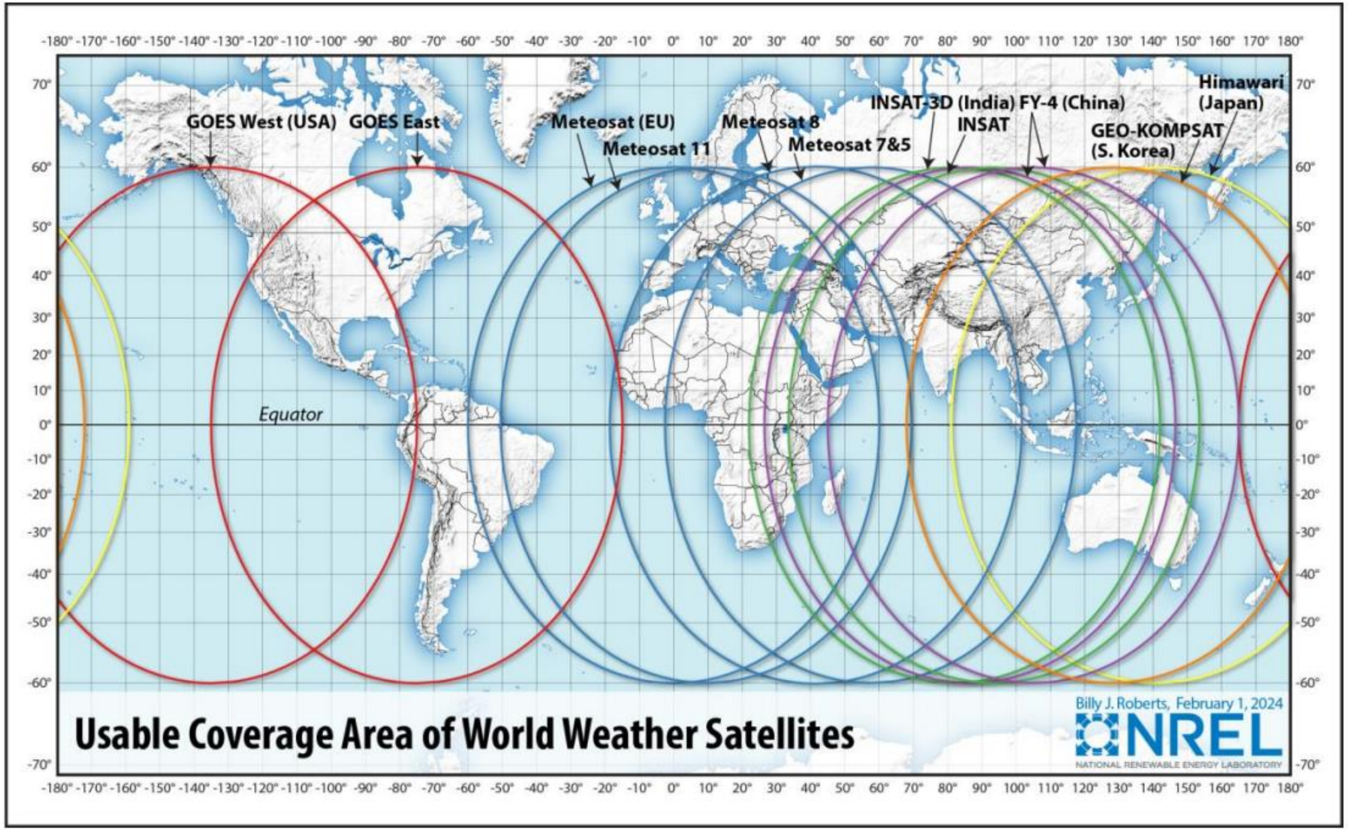
April 30, 2026

Measuring irradiance in Arctic conditions

Multi-component measurement stations



Satellite-derived irradiance



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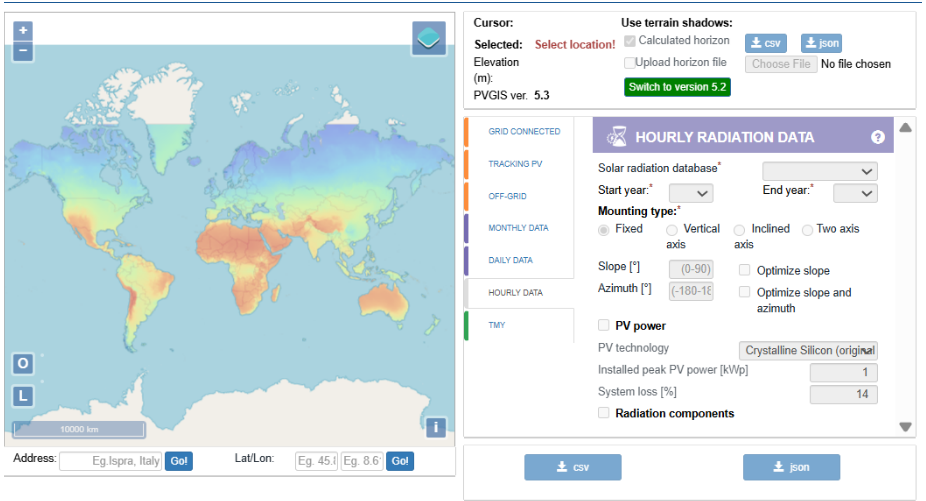
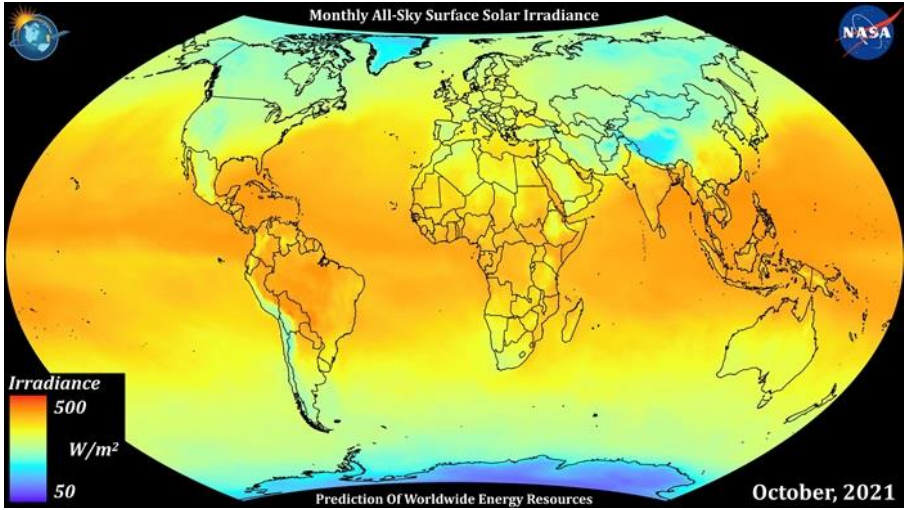
ERA5

- Type: reanalysis
- Period: 1940 – present
- Resolution: 31 km / 1 hour
- Access: website, pvlib-python



NASA POWER

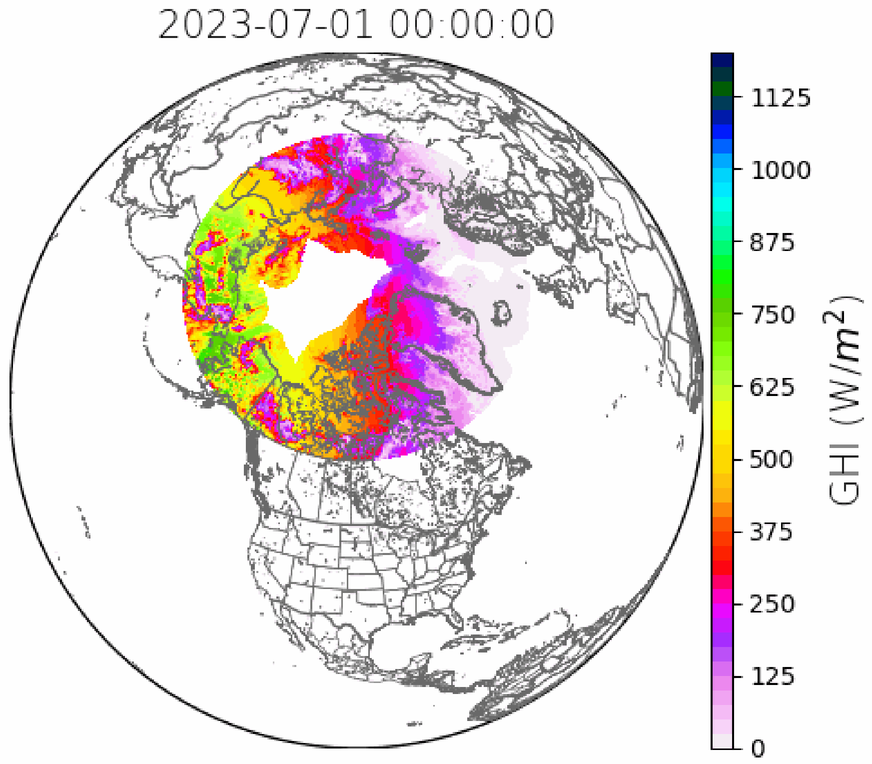
- Type: satellite (polar & geostationary
- Period: 2001 – onwards
- Resolution: 1.0° by 1.0° / 1 hour
- Access: website, API, pvlib-python



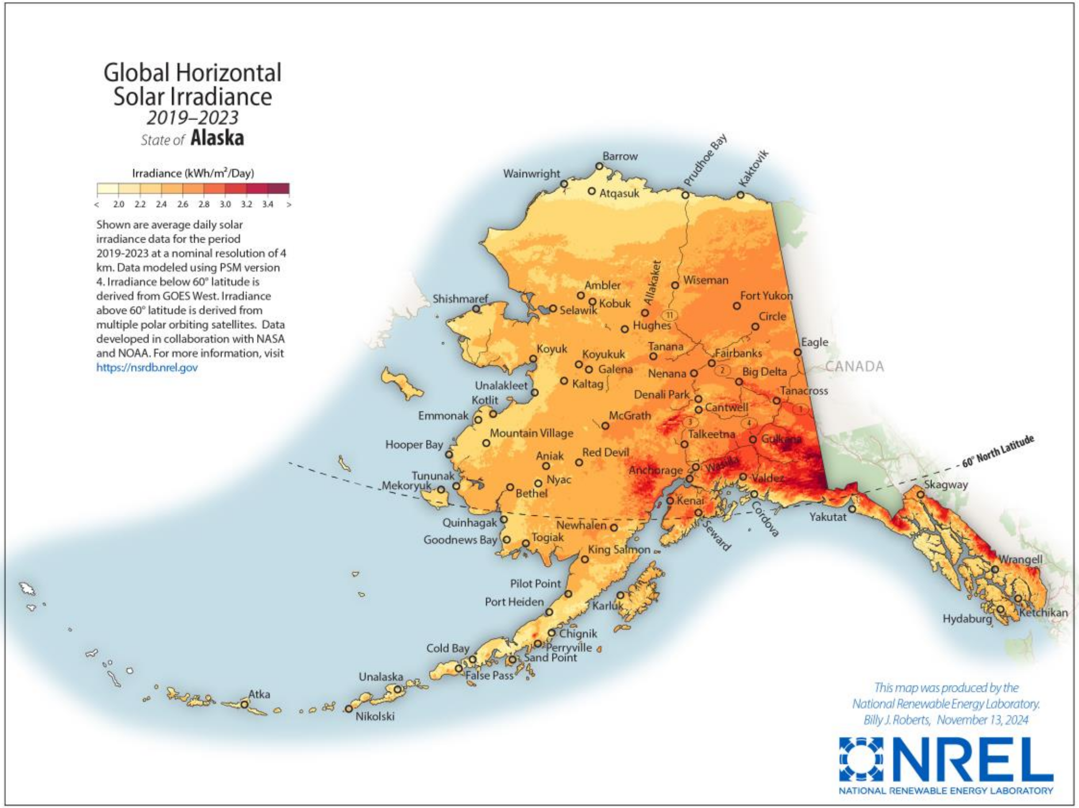
NSRDB Polar

- New dataset from 2025!

- Type: satellite (polar)
- Source: polar orbiting satellites
- Period: 2013 – onwards
- Resolution: 4 km / 1 hour



NSRDB Polar


Global Horizontal
Solar Irradiance
2019–2023
State of Alaska
Irradiance (kWh/m²/Day)
< 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 >
Shown are average daily solar irradiance data for the period 2019-2023 at a nominal resolution of 4 km. Data modeled using PSM version 4. Irradiance below 60° latitude is derived from GOES West. Irradiance above 60° latitude is derived from multiple polar orbiting satellites. Data developed in collaboration with NASA and NOAA. For more information, visit https://nsrdb.nrel.gov
Barrow
Wainwright
Atqasuk
Prudhoe Bay
Kaktovik
Wiseman
Ambler
Kobuk
Selawik
Shishmaref
Fort Yukon
Circle
Hughes
Allakaket
Eagle
Koyuk
Koyukuk
Galena
Tanana
Fairbanks
Nenana
Big Delta
CANADA
Unalakleet
Kaltag
Denali Park
Tanacross
Kotlit
Emmonak
McGrath
Cantwell
Mountain Village
Talkeetna
Gulkana
Hooper Bay
Aniak
Red Devil
60° North Latitude
Anchorage
Wasilla
Valdez
Skagway
Tununak
Mekoryuk
Nyac
Bethel
Kenai
Cordova
Yakutat
Quinhagak
Newhalen
Seward
Goodnews Bay
Togiak
King Salmon
Wrangell
Pilot Point
Port Heiden
Karluk
Ketchikan
Hydaburg
Chignik
Perryville
Cold Bay
Sand Point
False Pass
Unalaska
Atka
Nikolski
This map was produced by the National Renewable Energy Laboratory. Billy J. Roberts, November 13, 2024
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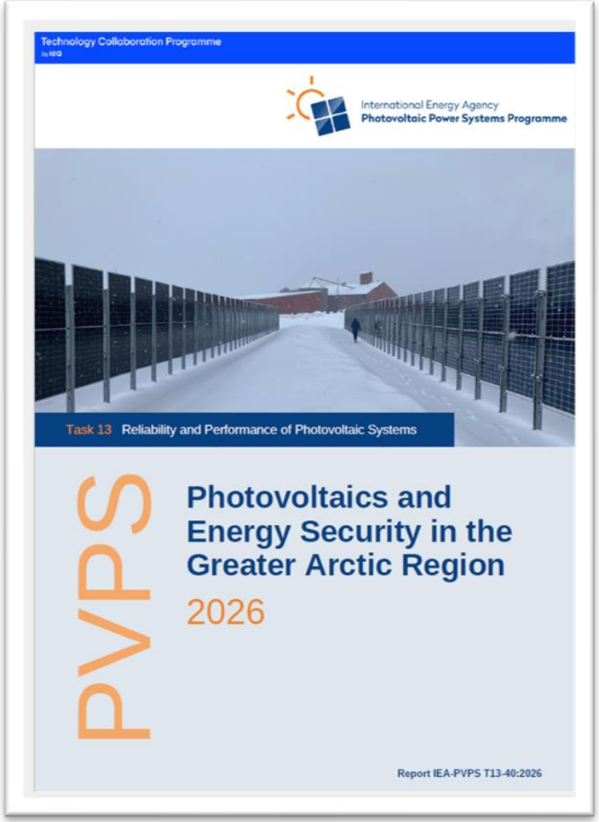
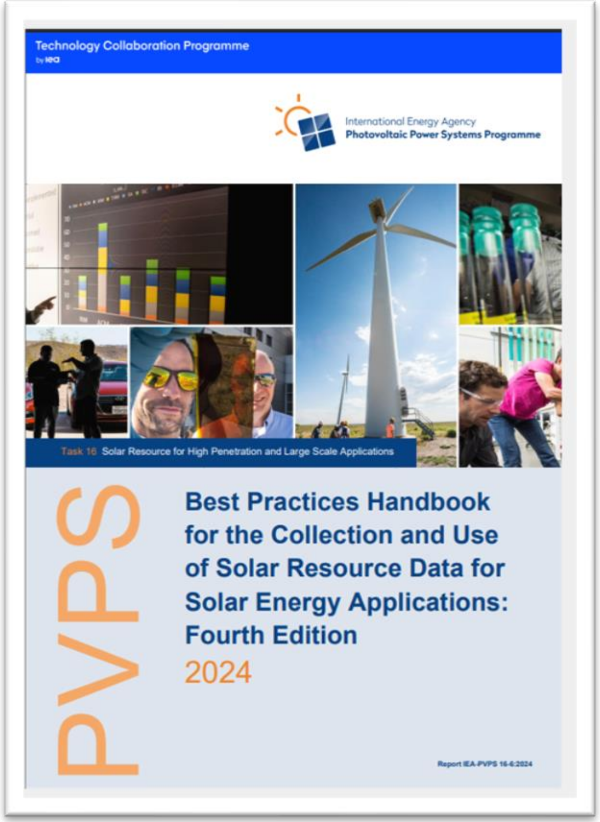
Further information





Photovoltaics and Energy Security in the Greater Arctic Region

Sandia National Laboratories Joshua S. Stein, et al.

Report IEA-PVPS T13-40:2026, February 2026

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4. Design and Modeling Considerations

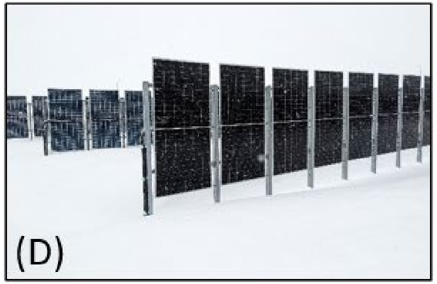
Example High-Latitude PV Deployments

South-facing fixed-tilt
Luleå, Sweden

Single-axis tracker
Lillestrøm, Norway

Dual-axis tracker
Fairbanks, USA

E-W vertical
Luleå, Sweden



Rooftop
Fairbanks, USA

Building integrated
Iqaluit, Canada

Artistic
Piteå, Sweden

Fairbanks, USA

Design Adaptations for High Latitudes

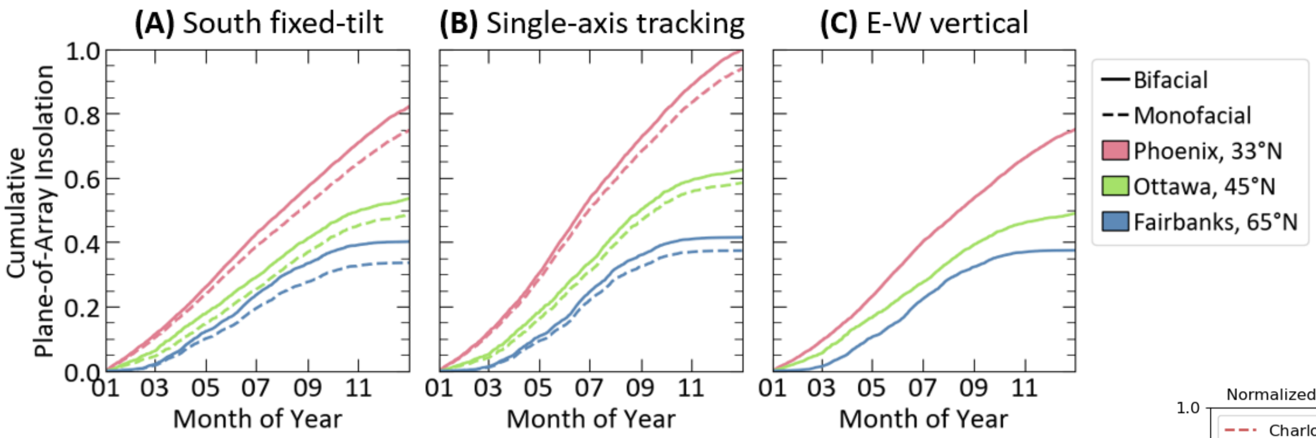
- Fixed-tilt preferred — simpler, more reliable in freeze-thaw cycles
- Tracking systems face cold-temperature reliability issues
- Larger row spacing needed due to low solar elevation angles
- Higher mounting heights to allow snow shedding
- Snow fences may be needed around ground-mounted arrays
- Bifacial modules recommended — leverage albedo & diffuse light
- Vertical E-W bifacial systems: capture wide azimuth range
- Vertical arrays also shed snow effectively

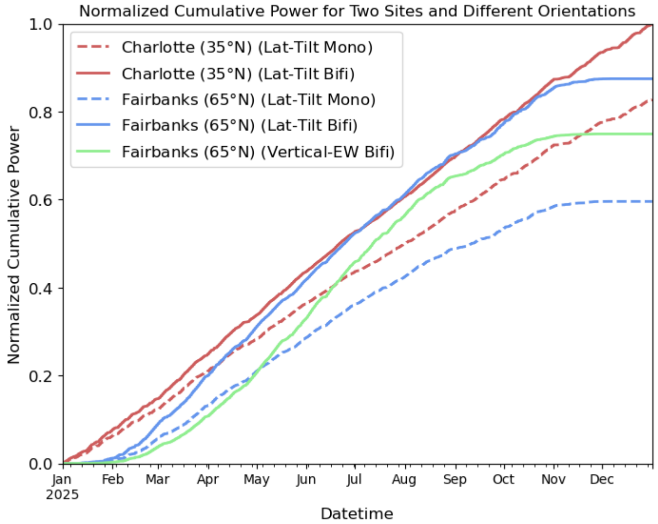
Vertical Bifacial PV for High Latitudes

- Capture low-angle sunlight from wide azimuth range
- Better match to daily electricity demand profile
- Improved building integration (façades)
- Substantially reduced snow accumulation losses
- E-W vertical produces more at morning/evening peaks

Vertical rooftop arrays in Norway. Photo credit: Over Easy Solar.

Cumulative POA Insolation by System Type





- Bifacial fixed-tilt in Fairbanks reaches ~90% of Charlotte monofacial yield
- Cold temps + snow albedo offset lower irradiance
- Vertical E-W bifacial in Fairbanks: ~65% of Charlotte reference
- Simulated with pvlib-python + SAPM model

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Modeling & Design Challenges

- Critical for financial planning, monitoring, and design decisions
- Higher uncertainty due to limited data and model validation >60°N
- Increased error for cloudy conditions and high-albedo environments
- Models less validated for vertical and façade systems
- Economic modeling complicated by remote location costs
- Northern Canada: equipment delivered by barge, airplane, or ice roads
- Ice road seasons narrowing due to warming climate
- Adapt models with snow loss algorithms and local sky coefficients

5. Performance in Extreme Cold

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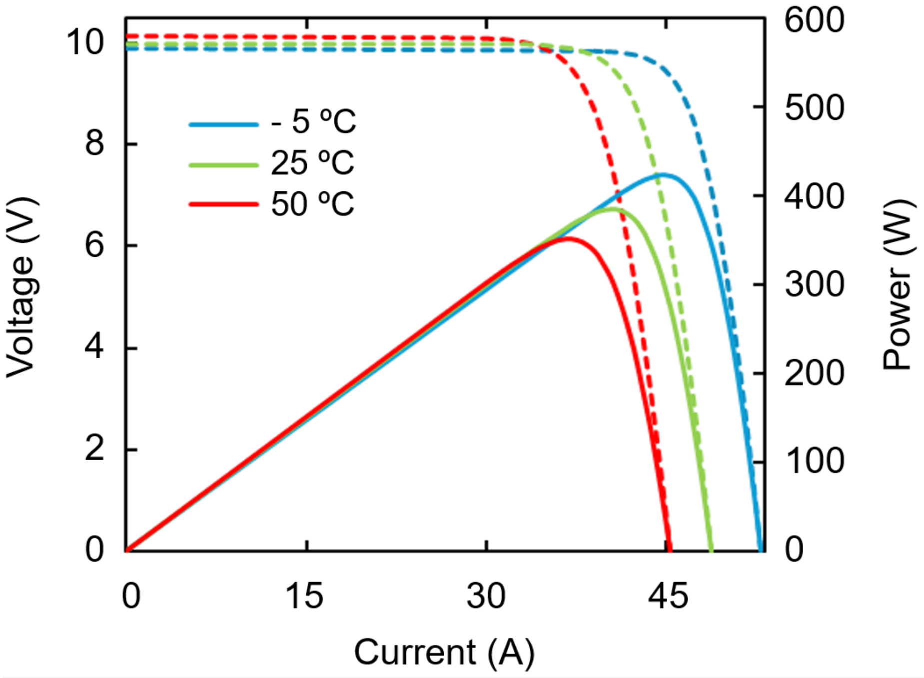
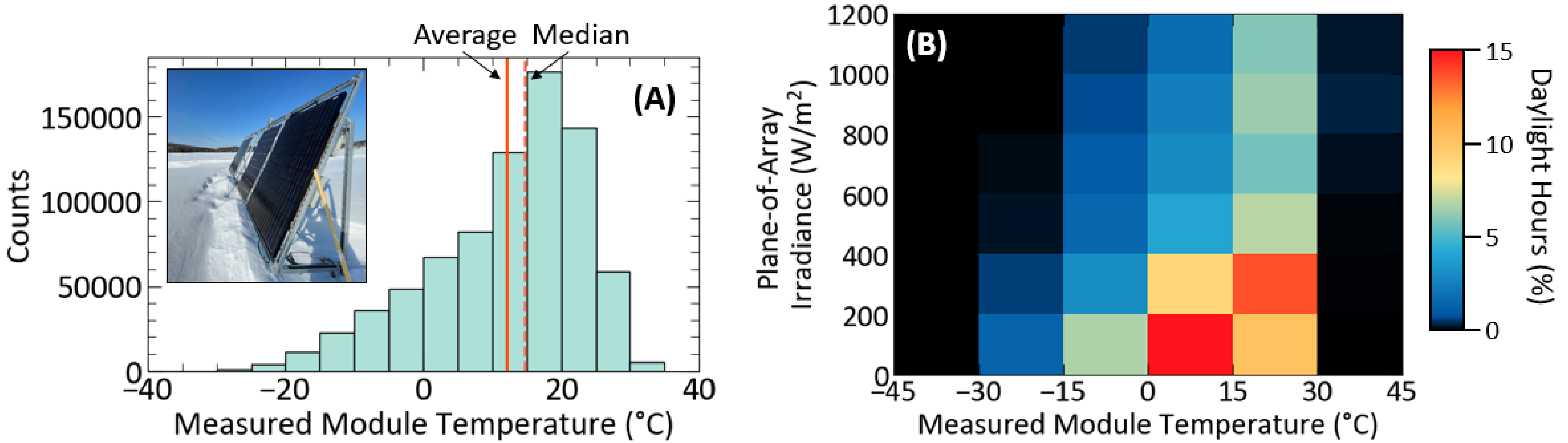
PV Performance Improves in Cold Temperatures

- Semiconductor bandgap widens at lower temps → higher voltage
- c-Si power temp coefficients: -0.25 to -0.35 %/°C
- At -5°C, module power output higher than at 25°C STC
- TOPCon/POLO cells: lower temp coefficients than PERC
- Some HJT cells show nonlinear behavior below -10°C



Real-World Module Temperatures: Fairbanks, AK



- Most operating hours in Fairbanks: 0-200 W/m² and 0-15°C

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Foundations and Frozen Ground Challenges

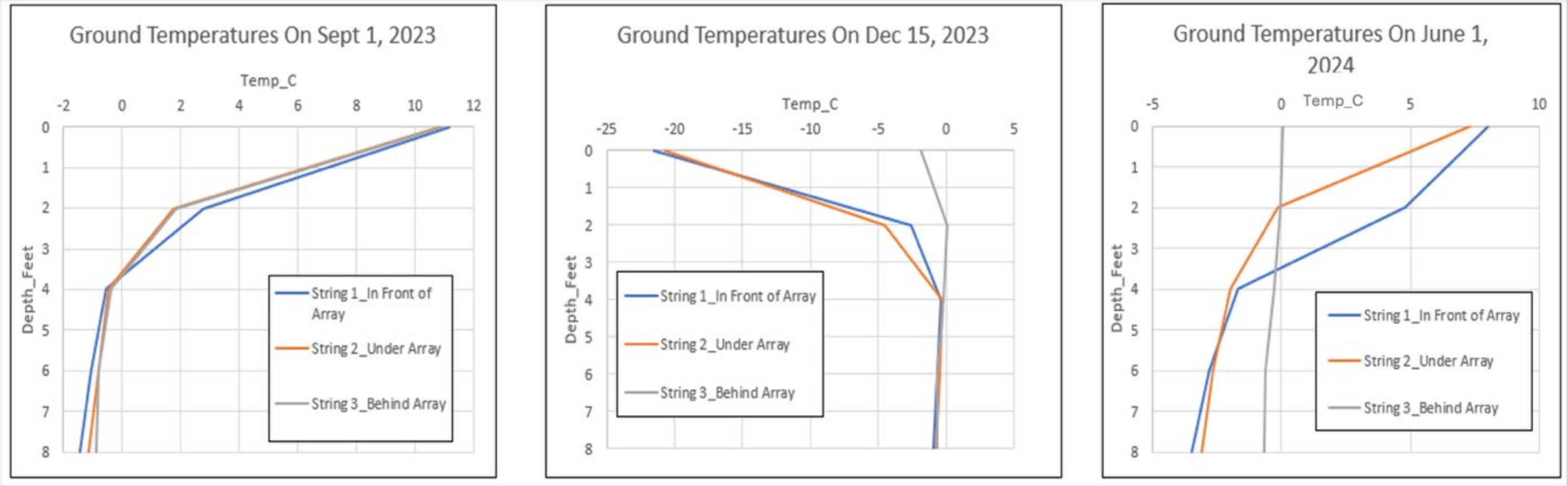
- Frost heaving: water freezes, expands, lifts/shifts ground
- PV racking causes deeper freezing underneath arrays
- Less snow insulation + metal piles = thermal conduits
- Luleå (66°N): racking damage first winter after install
- Fairbanks (65°N): piles jacked out of ground after 2 years
- Detailed geotechnical surveys specific to PV are essential
- Lesson: spend on geotechnical upfront — cheaper than repairs

563-kW array in Fairbanks, AK

Snow Drifting and Permafrost Impacts

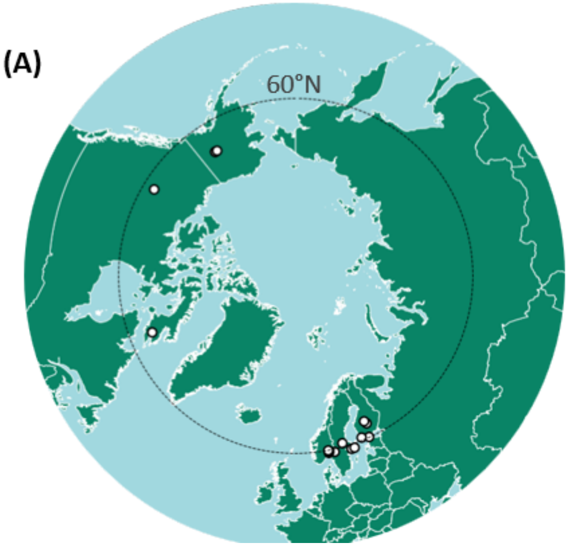
- Arrays act as snow fences — drifts form behind rows
- Kotzebue, AK: ~3m snow drift behind array
- Snow insulates ground → warms permafrost
- Can cause structural instability long-term
- Ground temp monitoring underway since July 2023

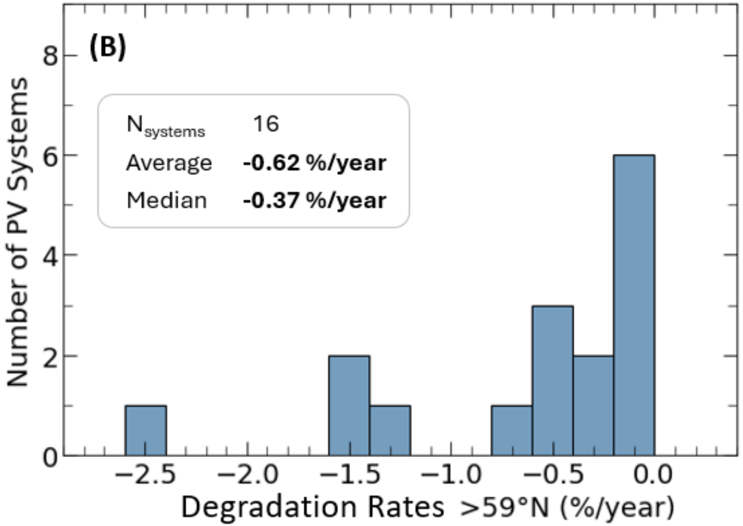
Ground Temperatures Around Solar Array



- Dec 2023: large temp differences by position
- Colder under/in front of array (less snow insulation)
- Warmer behind array (snow drift insulates ground)
- June 2024: warmer near foundation (metal heat conduction)
- Long-term effect: permafrost warming under drift zones

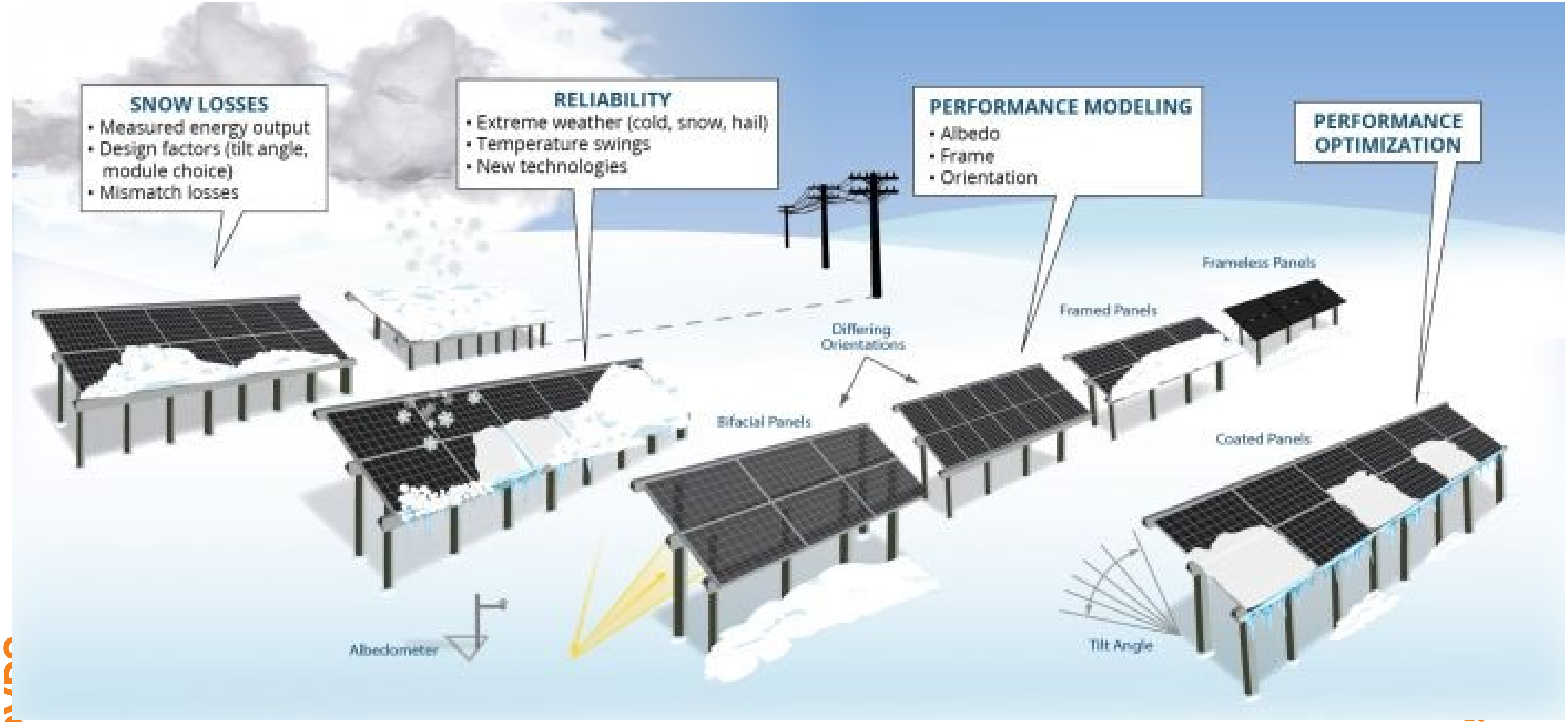
Lower Degradation Rates in Cold Climates





- Median PLR >59°N: -0.37%/yr (n=16)
- vs. continental USA median: -0.75%/yr
- High temps & UV that drive degradation are suppressed
- Main stressors: snow load, freeze-thaw, moisture ingress
- Data remains very scarce >60°N

6. Snow and Ice Accumulations

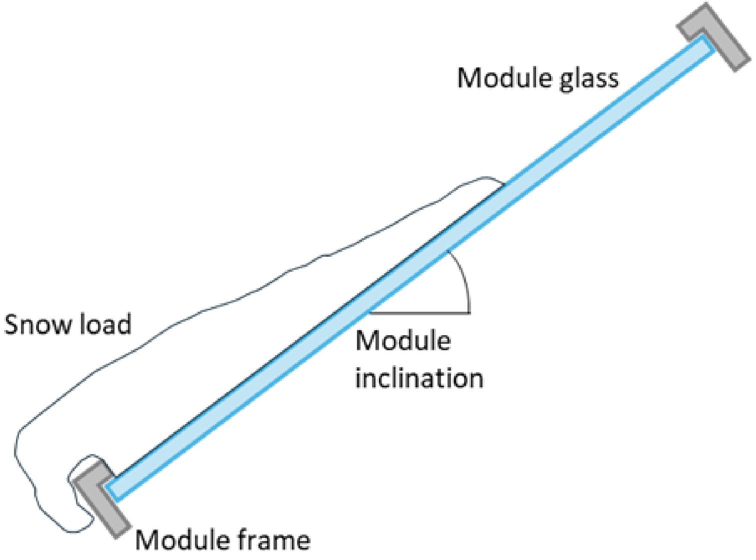

SNOW LOSSES
• Measured energy output
• Design factors (tilt angle, module choice)
• Mismatch losses
RELIABILITY
• Extreme weather (cold, snow, hail)
• Temperature swings
• New technologies
PERFORMANCE MODELING
• Albedo
• Frame
• Orientation
PERFORMANCE OPTIMIZATION
Frameless Panels
Framed Panels
Differing Orientations
Bifacial Panels
Coated Panels
Albedometer
Tilt Angle

Snow-Deposited Soiling

- Snow traps atmospheric particles as it falls
- If snow melts in-place (no shedding), soiling deposits remain
- A winter's worth of particles on module surface
- Impact observed but not well-studied in literature
- Obstructive frame profiles prevent shedding → more soiling

Mechanical Reliability Under Snow Loads

- Heavy loads → glass cracking, cell damage, frame separation
- IEC 61215-2: uniform test load ≥2400 Pa (5400 Pa for heavy snow)
- IEC 62938: non-uniform snow load testing (2020)
- Real-world: uneven distribution concentrates at lower edge
- Below -20°C: modules fail at much lower loads than rated
- EVA glass transition at ~-15°C reduces stress buffering
- POE/PDMS encapsulants: glass transition at -40°C or lower



Snow Mitigation: Active and Passive Solutions

Passive Solutions

- Ice-phobic / hydrophobic coatings
- Steeper tilt angles for gravity shedding
- Snow fences to control drift patterns
- Frameless modules reduce edge buildup
- System layout optimization

Active Solutions

- Surface heating (resistive wires / reverse current)
- Mechanical snow removal
- Chemical treatments (environmental concerns)
- All require external power
- Must balance energy cost vs. energy recovered

Thank you

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