SNOW REFERENCE DATA PLANNED TO BE USED IN

snowpex+

esa

THE SATELLITE SNOW PRODUCTS INTERCOMPARISON AND EVALUATION EXERCISE

SnowPEx CCN2

In Situ Reference Data

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SnowPex+ Virtual Meeting, 3 February 2021

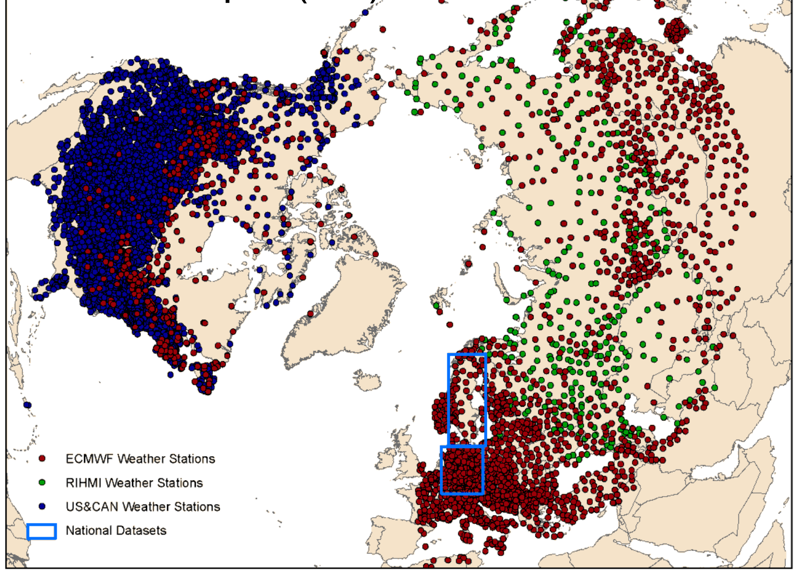
SnowPEx Consortium:

enveo Canada FMI SYKE esa snowpex

In situ reference data

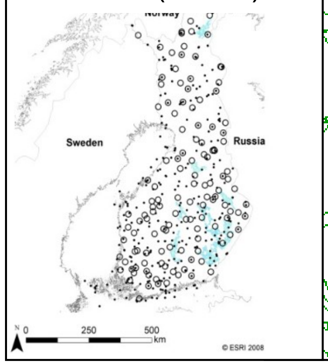
SNOW COVER

1. Snow depth (SD)

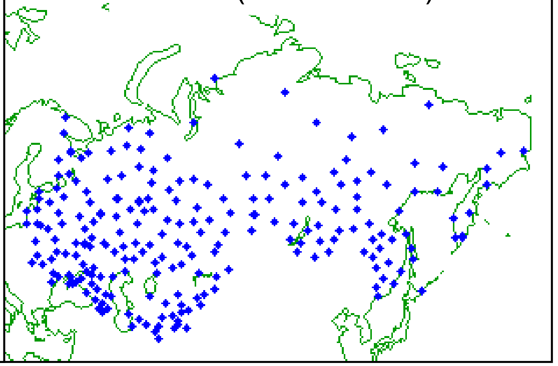


2. Snow cover fraction (SCF) from snow transects

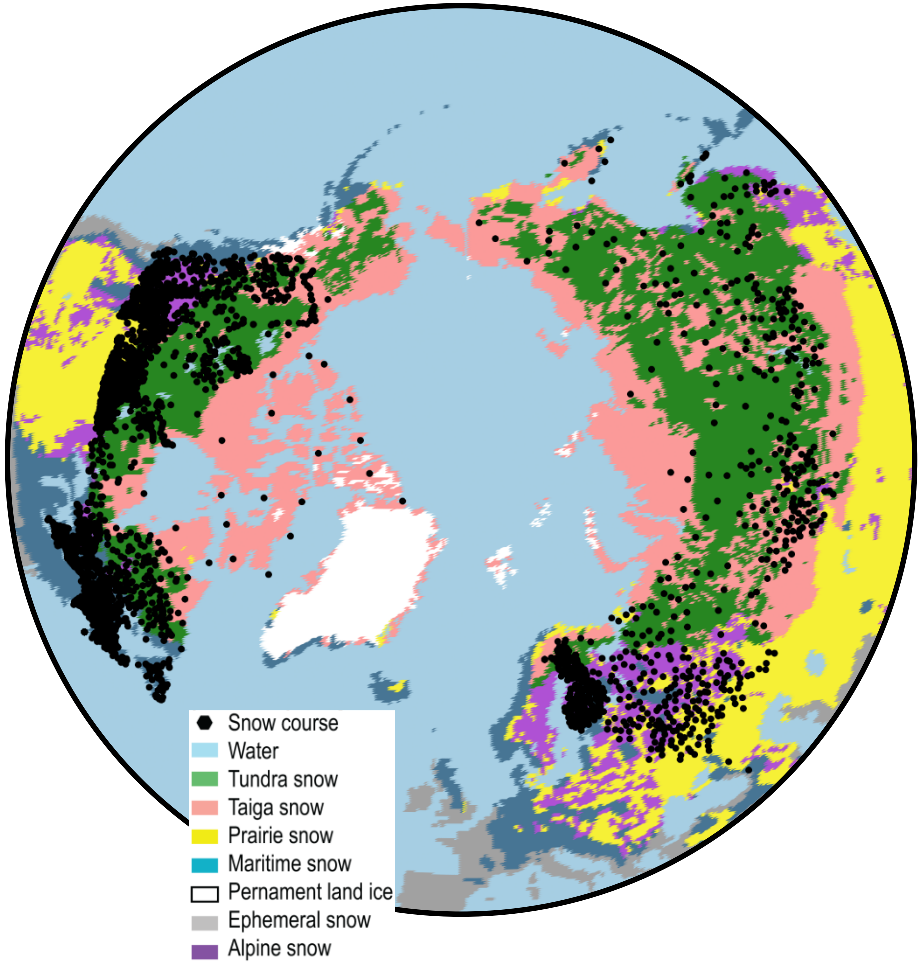
Finland (SYKE)



Russia (RIHMI-WDC)



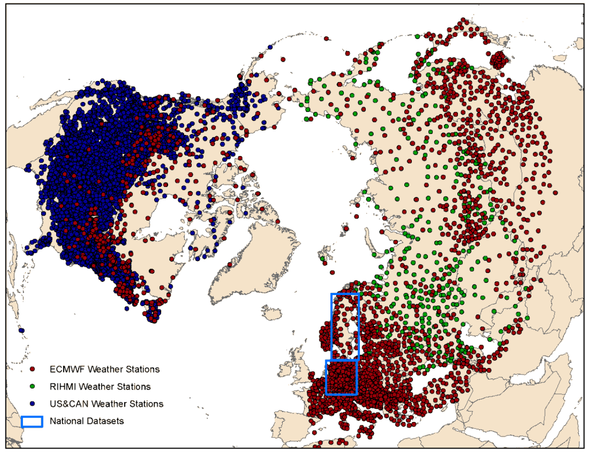
SNOW WATER EQUIVALENT



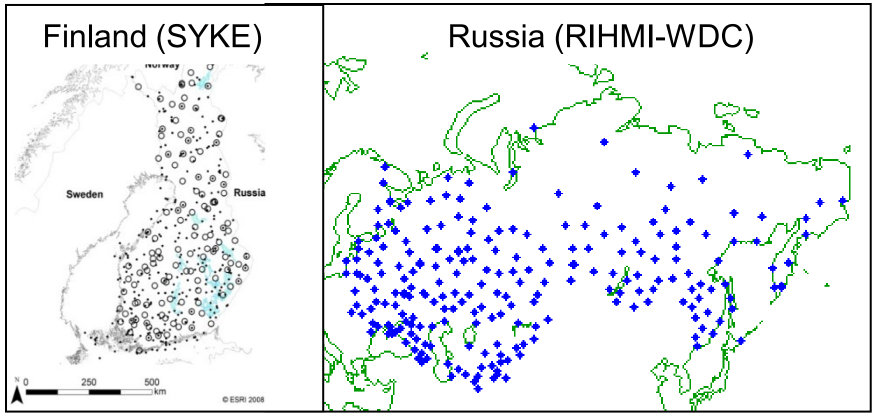
SWE – snow course / snow transect

In situ snow cover data – considerations for validation

- Synoptic snow depth: daily frequency, converted to binary snow/no snow for validation.
- SCF data: monthly or 10 day frequency depending on the region. Limited spatial and temporal coverage. Can be used ’as is’ as part of a supplemental evaluation or converted to binary for SCE.



Snow Depth



Snow cover fraction from snow transects

SCE validation technique

- In situ snow depth data and snow cover product grid cells are converted to binary snow/no snow.

Fig. Conversion of in situ and product snow depth to binary for validation

Criteria for products
if SCF≥25% then "snow" else "no snow"
if SCF≥15% then "snow" else "no snow"

Criteria for in-situ
if SD>0cm then "snow" else "no snow"
if SD≥2cm then "snow" else "no snow"
if SD≥15cm then "snow" else "no snow"

in-situ	Product	
	snow	No-snow
snow	True Positives (TP)	False Negatives (FN)
no-snow	False Positives (FP)	True Negatives (TN)

To binary metrics…

Snow cover extent – validation against in situ data

Table 1. Binary metrics applied in the in situ validation

Metric	Description	Special considerations for Nref_snow = TP+FN; Nref_nosnow = TN+FP; Ntot = TP+TN+FN+FP
Recall	TP / (TP + FN)	IF Nref_snow < 20 THEN Recall = 'not-defined'
Precision	TP / (TP + FP)	IF Nref_snow <20 or Nref_nosnow < 20 THEN Precision= 'not-defined'
False Alarm Rate	FP / (FP + TN)	IF Nref_nosnow / Ntot < 0.10 THEN False Alarm Rate = 'not-defined'
Hit Rate (Accuracy)	(TP + TN) / (TP + TN + FP + FN)	IF Nref_snow < 20 or Nref_nosnow < 20 THEN Hit Rate = 'not-defined'
Critical Success Index	TP / (TP + FN + FP)	IF Nref_snow < 20 or Nref_nosnow < 20 THEN Critical Success Index= 'not-defined'
F-score	2 * TP / (2 * TP + FP + FN)	IF Nref_snow < 20 or Nref_nosnow < 20 THEN F-score = 'not-defined'

SWE in situ reference data

- Snow course gathered by FMI and ECCC, archived @ http://snowpex.enveo.at for project use.
- Additional data may be added if available. Europe – data exist but unable to obtain as of yet.
- Measurements frequency: every ~2 weeks depending on the region.

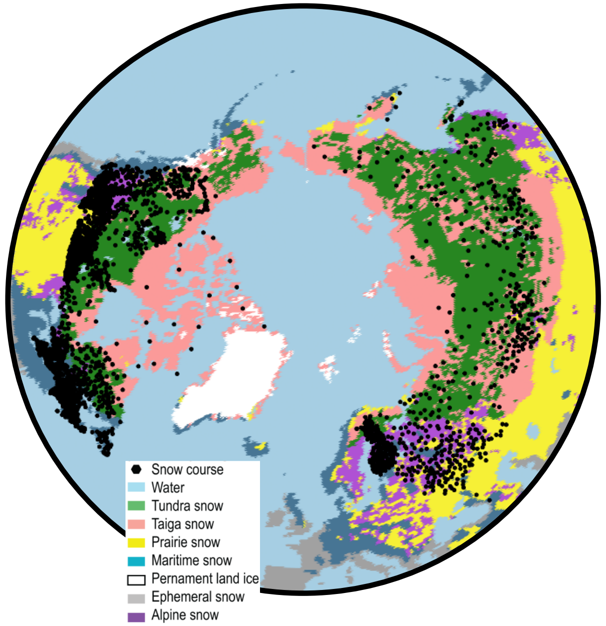


Table 2. SWE reference data housed on snowpex portal

Agency	Spatial coverage	Source
Environment and Climate Change Canada	Canada + transboundary	Brown et al. 2019 Vionnet, Mortimer et al. in prep.
Finnish Environment Institute (SYKE)	Finland	SYKE
RIHMI-WDC	Former soviet union, Russia 1990s - present	Bulygina et al., 2011
Maine Geological Survey	US state of Maine (Northeast)	Maine GS Open Data gis.maine.gov

SWE validation against in situ data

- Match product grid cell with collocated in-situ reference SWE measurement. Spatiotemporal aggregation to account for differences in sampling frequency.
- Statistics reported for each input dataset and by Sturm snow class at monthly and annual timescales.

Table 3. Metrics applied in the in situ validation

Bias	$b = \frac{1}{N}\sum_i (s_i - t_i)$
RMSE	$e = \sqrt{\frac{1}{N}\sum_i (s_i - t_i)^2}$
Correlation	$r = \frac{\sum_i (s_i - \bar{s})(t_i - \bar{t})}{\sqrt{\sum_i (s_i - \bar{s})^2 \sum_i (t_i - \bar{t})^2}}$

In situ reference data: Summary

- All datasets cover 2015-2020
- Synoptic SD -> SCE (on/off) validation
- SCF from snow courses -> potential supplemental SCF validation
- SWE from snow courses -> SWE validation
- **Additional data and regional evaluations:**
  – The better the spatial coverage of the reference data, the better the evaluation.
  – If high quality regional reference data are found or provided early in the project, regional evaluations could be considered.

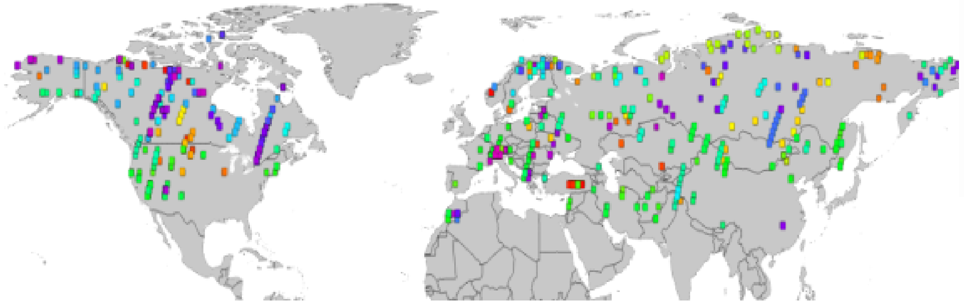
High-Resolution Reference Data Set

Lars Keuris, Thomas Nagler, Gabriele Schwaizer

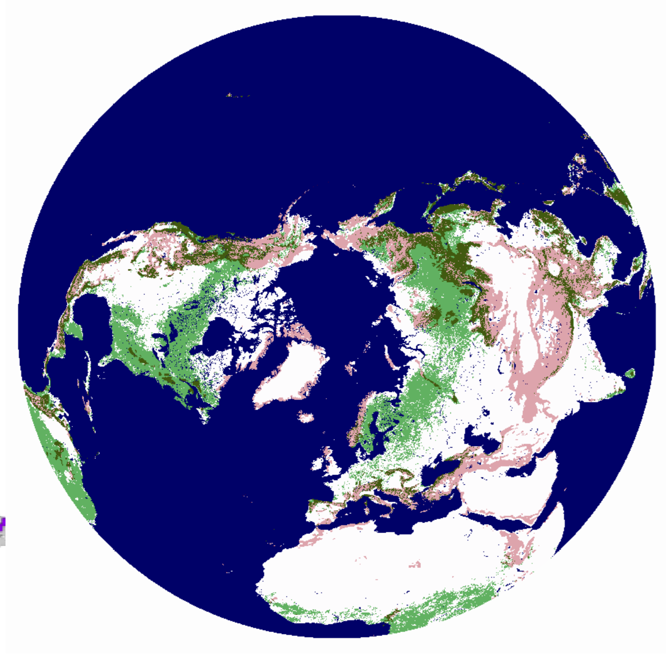
Data description & objective

- Reference data set compilation:
  - Size: 150+ cloud-free Landsat and Sentinel-2 scenes
  - Temporal coverage: 01.10.2014 – 30.09.2020
  - Spatial coverage: global
  - Covers different:
    - snow cover regimes
    - surface classes and climate zones
    - seasons

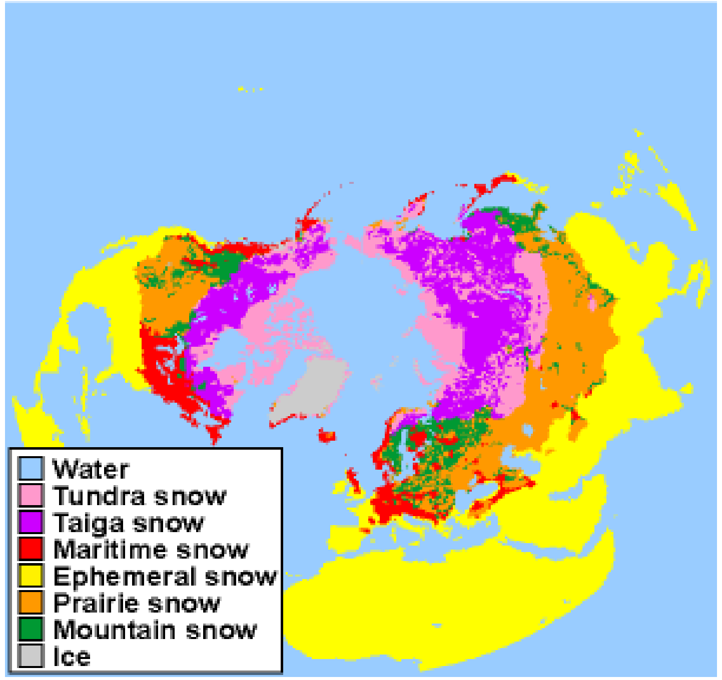
- Generation of a high-quality reference data set (using different algorithms) for intercomparison



LS dataset used in SnowPEx-I for period 1999 - 2014



Surface classes

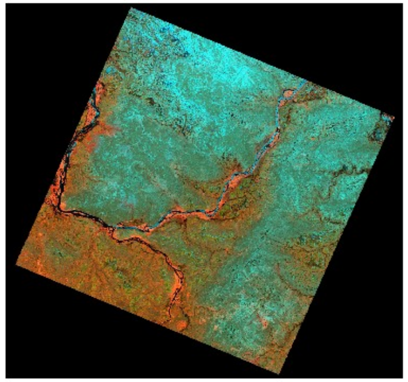


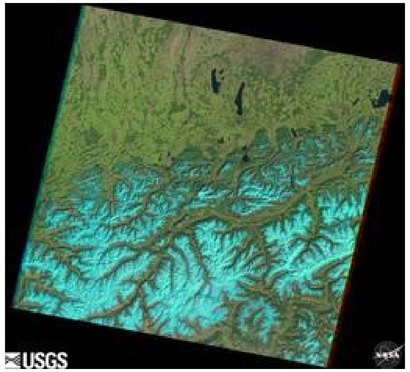
Climate classification of seasonal snow

Workflow

HR dataset
Landsat & Sentinel-2 scenes

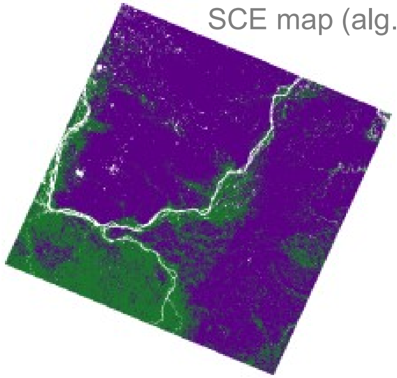
False colour composite Landsat-7



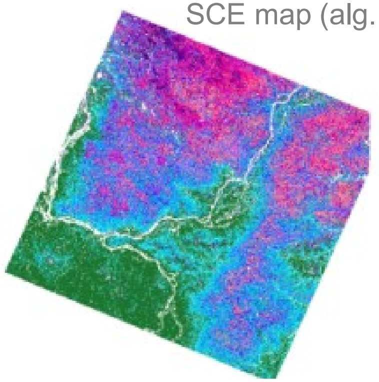


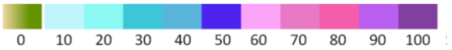
SCE generation
from **conventional** and **advanced** algorithms

SCE map (alg. 1)



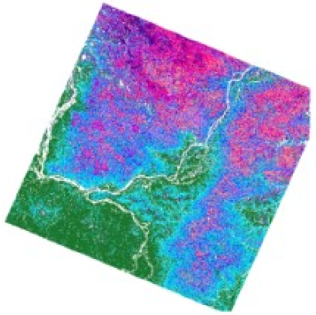
SCE map (alg. 2)



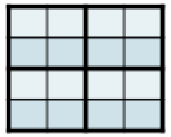


Preparation and aggregation
of the SCE maps

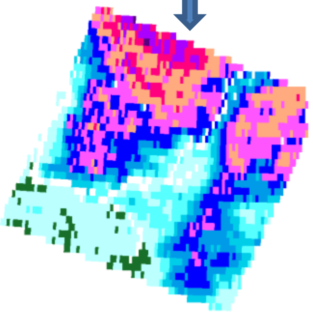
30 m



$$FSC_{MR_i} = \frac{1}{N_{cell}} \sum_{j=1}^{N_{cell}} FSC_j$$

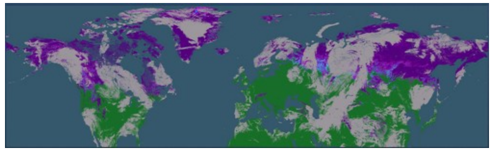


5 km



Intercomparison
of the reference SCE and participating SCE products for different surface classes

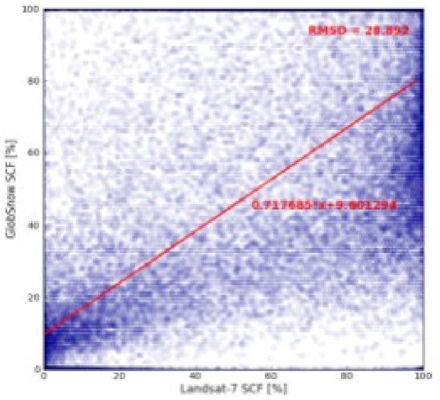
Globland NHEMI SCE



Statistical parameters
(next slide)

Intercomparison

- Pixel-by-pixel intercomparison
- Statistical paramaters for all relevant pixels per sub-class (combination):
  - Forested, non-forested, mountainous, plains
  - Sturm Climate Classes
  - FSC range
- Scatterplot



- In forested areas: comparison of the same thematic information
  - Snow on ground, viewable snow

Fractional Snow Extent products

Root Mean Square Error of FSC

$$RMSE = \sqrt{\frac{1}{N_{ui}} \sum_{j=0}^{y} \sum_{i=0}^{x} (FSC_{EXT}(i,j) - FSC_{REF}(i,j))^2}$$

Bias of FSC

$$BIAS = \frac{1}{N_{ui}} \sum_{j=0}^{y} \sum_{i=0}^{x} (FSC_{EXT}(i,j) - FSC_{REF}(i,j))$$

Total Snow Extent (in terms of pixels)

$$N_{equ} = \sum_{j=0}^{y} \sum_{i=0}^{x} \frac{FSC(i,j)}{100}$$

Correlation Coefficient of FSC

$$CorrCoef = \frac{\sum_{j=0}^{y} \sum_{i=0}^{x} \left(FSC_{EXT}(i,j) - \overline{FSC_{EXT}}\right)\left(FSC_{REF}(i,j) - \overline{FSC_{REF}}\right)}{\sqrt{\sum_{j=0}^{y} \sum_{i=0}^{x} \left(FSC_{EXT}(i,j) - \overline{FSC_{EXT}}\right)^2 \sum_{j=0}^{y} \sum_{i=0}^{x} \left(FSC_{REF}(i,j) - \overline{FSC_{REF}}\right)^2}}$$

Binary Snow Extent products

$$\mathit{Precision} = \frac{TP}{TP + FP} \qquad \mathit{Recall} = \frac{TP}{TP + FN}$$

$$\mathit{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$\mathit{Fscore} = 2 * \frac{Precision * Recall}{Precision + Recall} = \frac{2\,TP}{2\,TP + FP + FN}$$

		PRODUCT REF	
		SNOW	SNOW FREE
PRODUCT EXT	SNOW	True Positives (TP)	False Positives (FP)
PRODUCT EXT	SNOW FREE	False Negatives (FN)	True Negatives (TN)

40-years airborne gamma radiation SWE

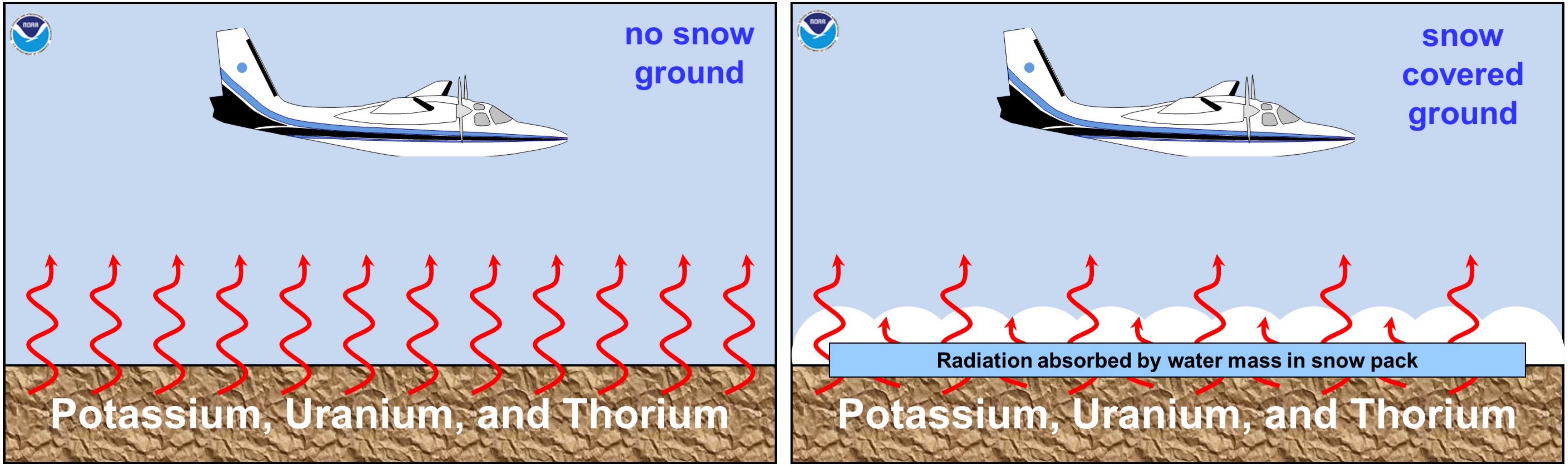
Eunsang Cho[1,2*], Jennifer Jacobs[3], Carrie Vuyovich[1], Carrie Olheiser[4]

[1]NASA GSFC, USA
[2]University of Maryland, USA
[3]University of New Hampshire, USA
4NOAA National Operational Hydrologic Remote Sensing Center, USA

Airborne Gamma SWE algorithm

The operational NOAA airborne snow survey provides gamma radiation SWE observations in 37 US states and 7 Canadian provinces from 1980 to present for snowmelt flood predictions and water supply outlooks (Carroll, 2001).

Terrestrial Gamma-ray attenuation algorithm (*Carroll, 2001*)



- The earth is emitting very small amounts of natural terrestrial gamma radiation isotopes.
- The gamma radiation is absorbed by water mass (SWE) in snowpack.

Gamma SWE's features

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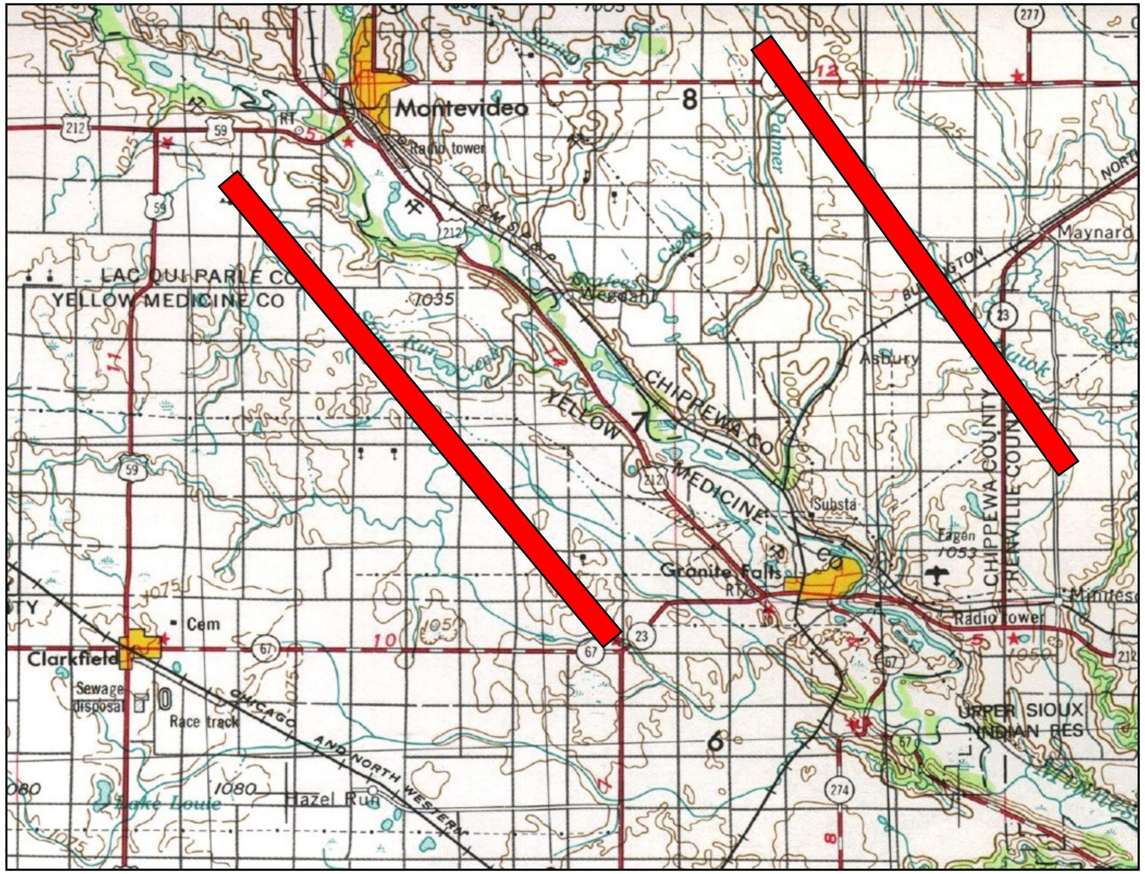
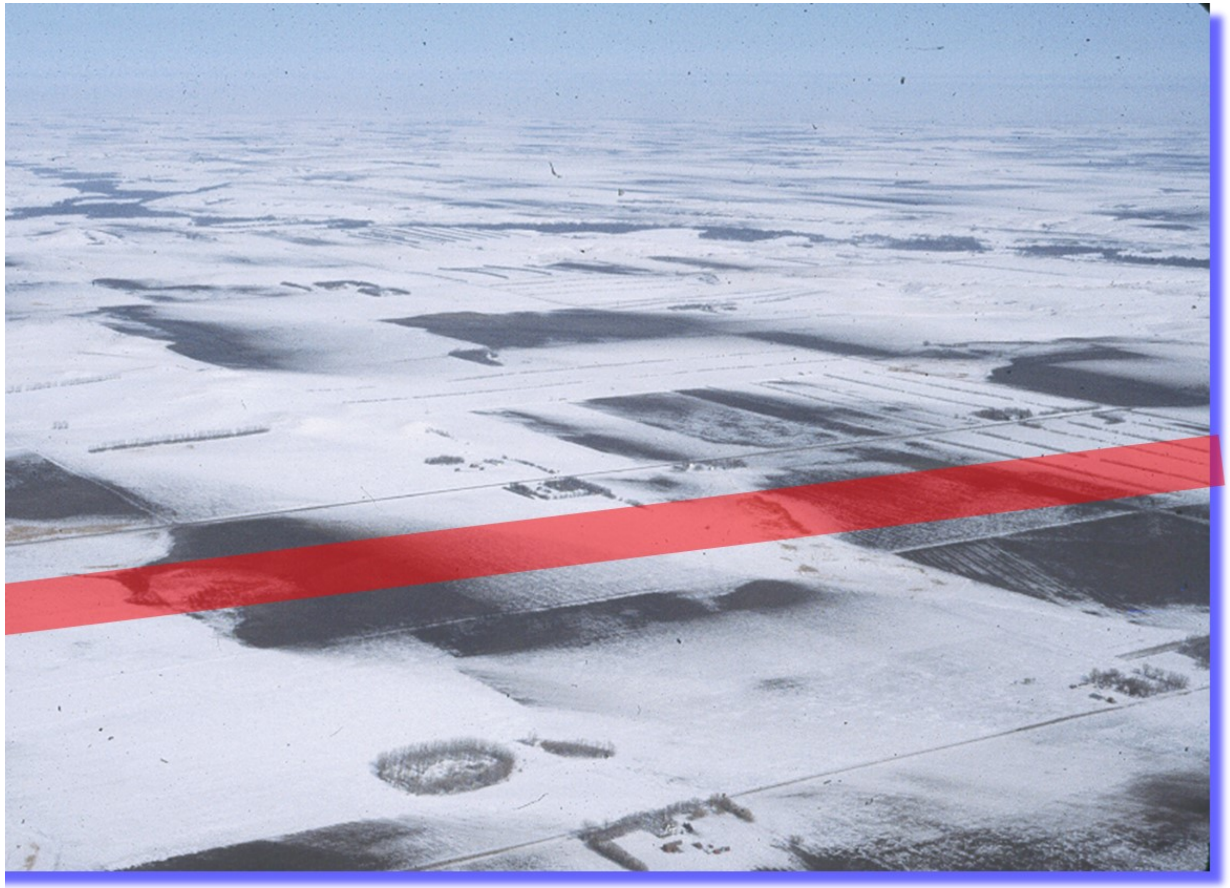
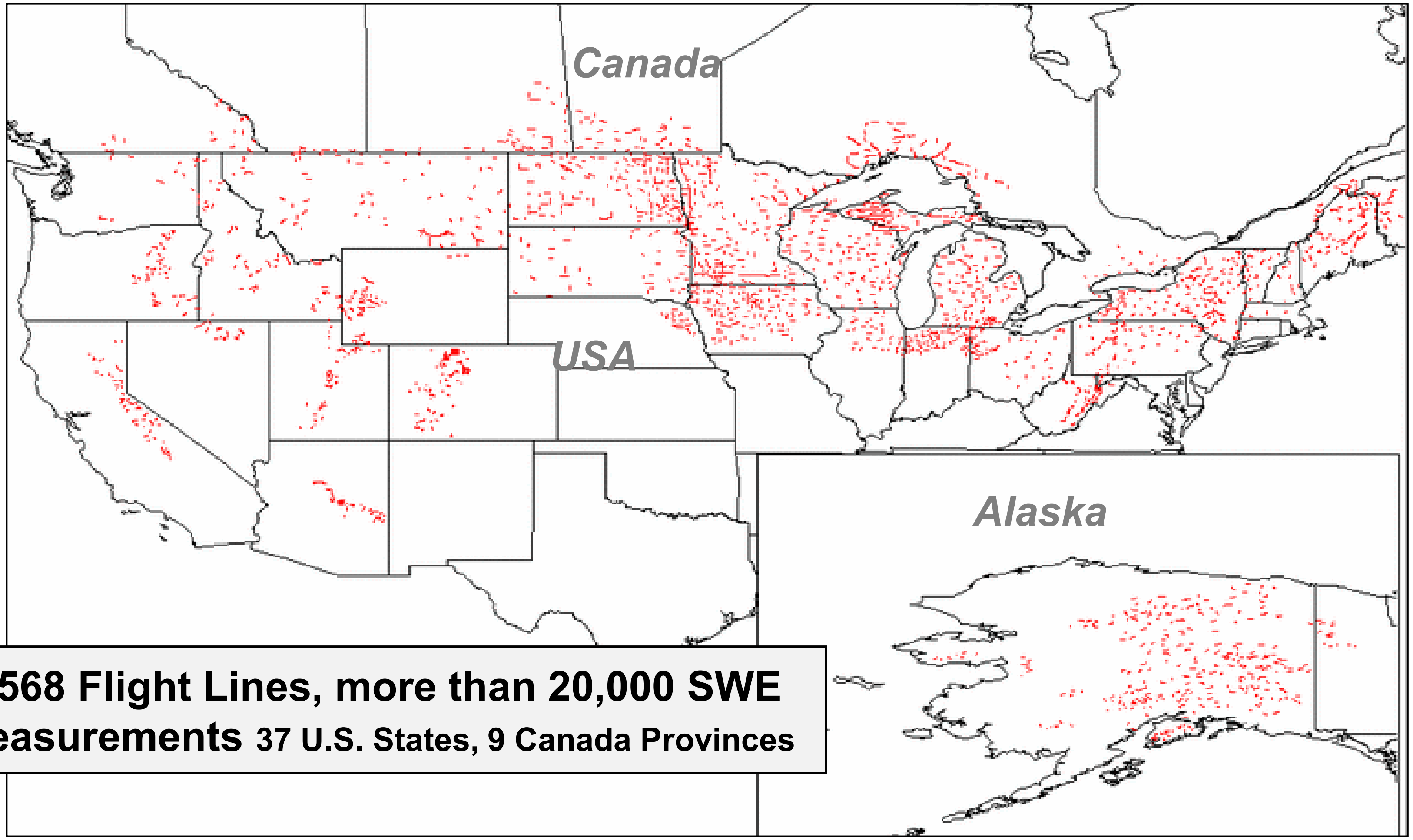




1. Typical Gamma Flight Line (5 km^2 area with 16 km long by 300 m wide) provides a single SWE.
2. Airborne gamma measurements integrate shallow and deep snowpack over a path.
3. If ground ice exists, this also acts like SWE attenuating gamma radiation.

Gamma SWE Temporal and Spatial Coverage

1. Long-term SWE record from 1980 to present (42 years; 1- 4 times per winter)



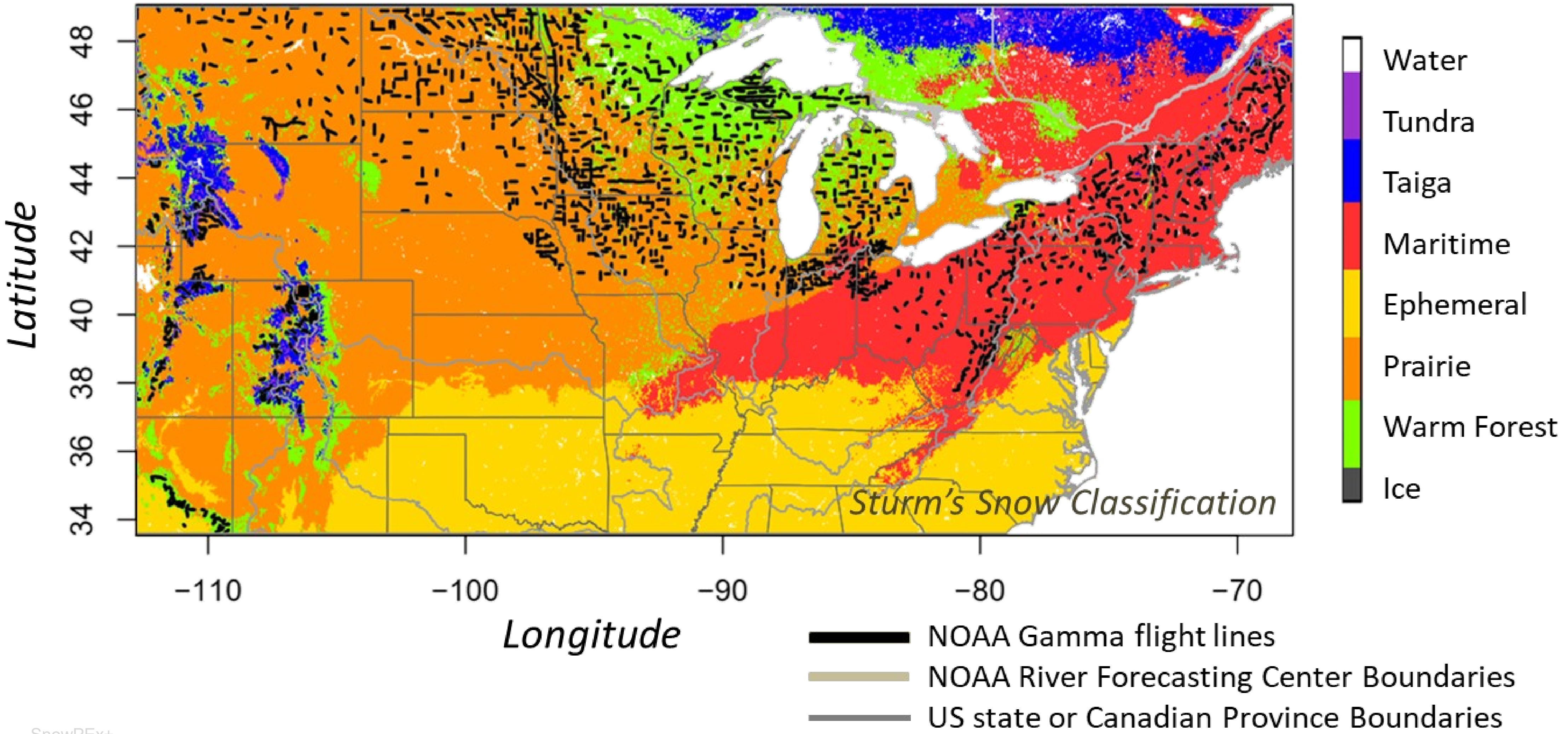
2568 Flight Lines, more than 20,000 SWE measurements 37 U.S. States, 9 Canada Provinces

2. Reliable SWE as reference across challenging environments (e.g. forest, wet snow, mountains)

Gamma SWE as reference data sets (*two examples*)

1) Evaluation of three observation-based long-term SWE products for 1982-2017 (*Cho et al., 2020*)

1. SSM/I-SSMIS satellite SWE, 2. Globsnow-2 SWE, 3. UA (University of Arizona) SWE



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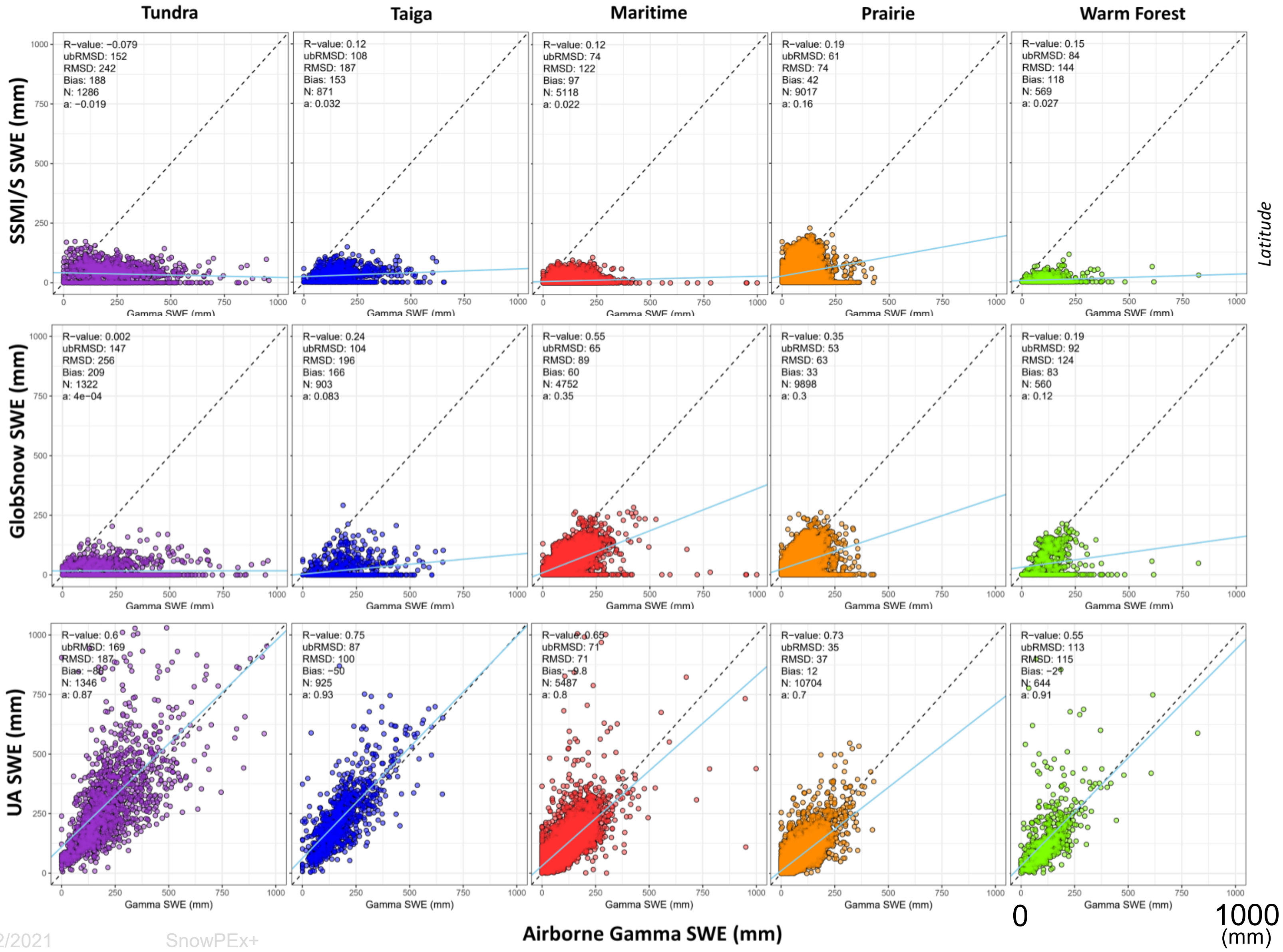
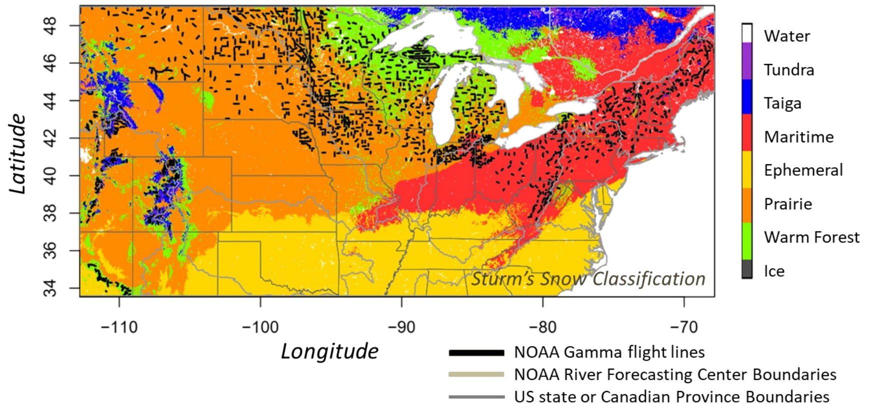


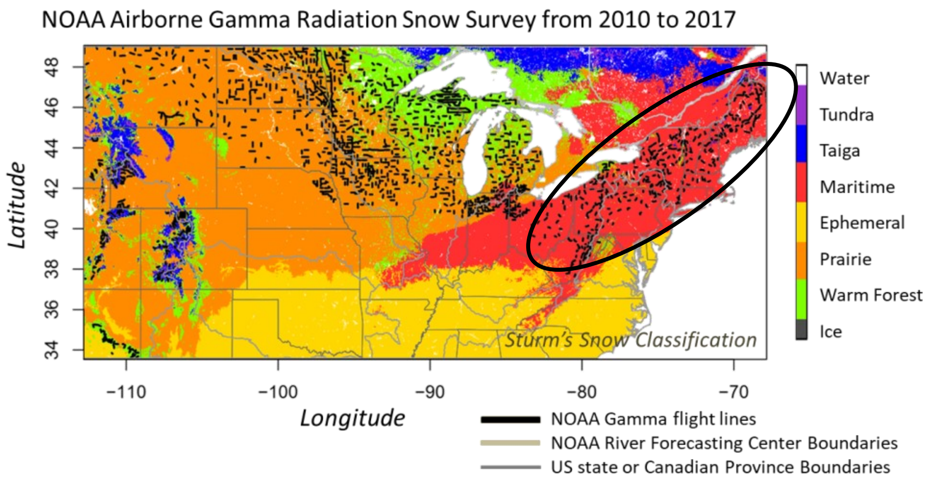


✓ The historical **40-year and ongoing** NOAA airborne gamma SWE record can be used as independent, reference long-term reliable SWE in various environments (including mountainous regions such as Colorado Rocky & Sierra Nevada, California).

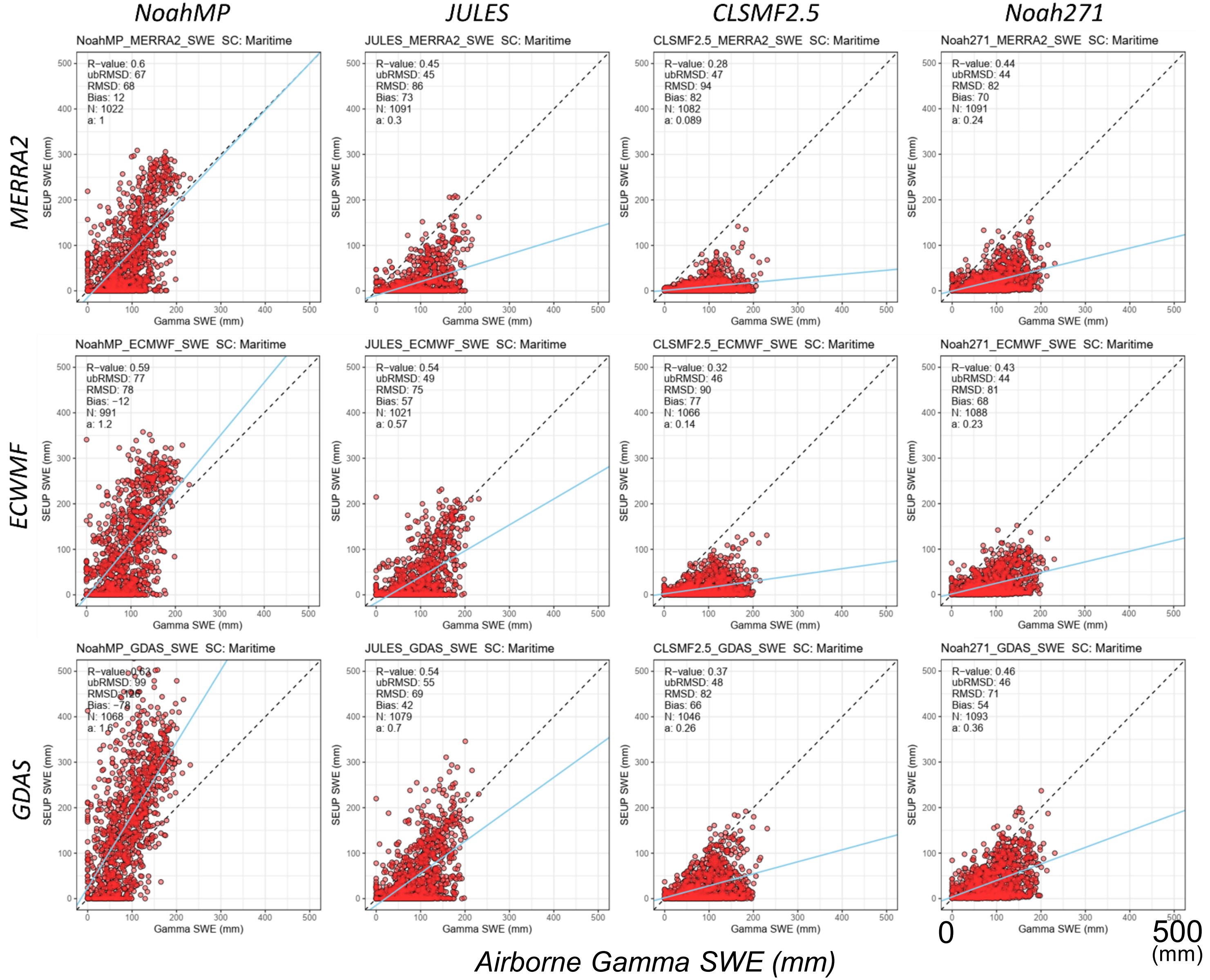
Gamma SWE as reference data sets

2) Evaluation of twelve SWE products from 4 LSMs and 3 forcing data sets from 2010 to 2017 (*Cho et al., in preparation*)

Maritime Class over northeastern U.S.



- ✓ Airborne gamma SWE can provide reliable SWE values in **densely forested** regions.
- ✓ Using gamma SWE, SnowPEx+ community can evaluate new SWE products by each snow classes/land cover types.



Product Summary Information Gamma SWE

Product name	Gamma SWE, NOAA Airborne Gamma Radiation SWE
Satellite & Sensor	Airborne-based gamma radiation detector
Retrieval Algorithm	Terrestrial Gamma-ray attenuation algorithm (Carroll, 2001; Cho et al., 2020)
Snow Parameter*	SWE
Spatial Coverage	Entire USA including Alaska and southern Canada (2568 flight lines, >20,000 SWE measurements)
Map Projection	-
Pixel spacing	Flight path; 5 km^2 with 300 m wide and 16 km long
Temporal Coverage	1980 – present (42 years)
Temporal Frequency	1 - 4 times per flight line during a winter period
Accuracy Parameter **	RMSE **Fields**: 9 mm (10%; SWE range: 40 – 150 mm) & **Forest**: 23 - 60 mm (13%; SWE range: 200 – 460 mm) (*Carroll, 2001; Carroll and Vose, 1984; Cho et al., 2020; Glynn et al., 1988*)
Accuracy Information ***	Assessment with ground-based SWE measurements over gamma flight paths.
Webpage	https://www.nohrsc.noaa.gov/snowsurvey/
Contact Point:	Eunsang Cho (eunsang.cho@nasa.gov), Carrie Olheiser (carrie.olheiser@noaa.gov)
References	Tom Carroll (2001) Airborne Gamma Radiation Snow Survey Program A User's Guide, NOAA white paper Eunsang Cho, Jennifer Jacobs, & Carrie Vuyovich (2020) The value of long-term (40 years) airborne gamma radiation SWE record, *Water Resource Research*

Thank you.

If you have any questions or comments, please email me!

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snowpex

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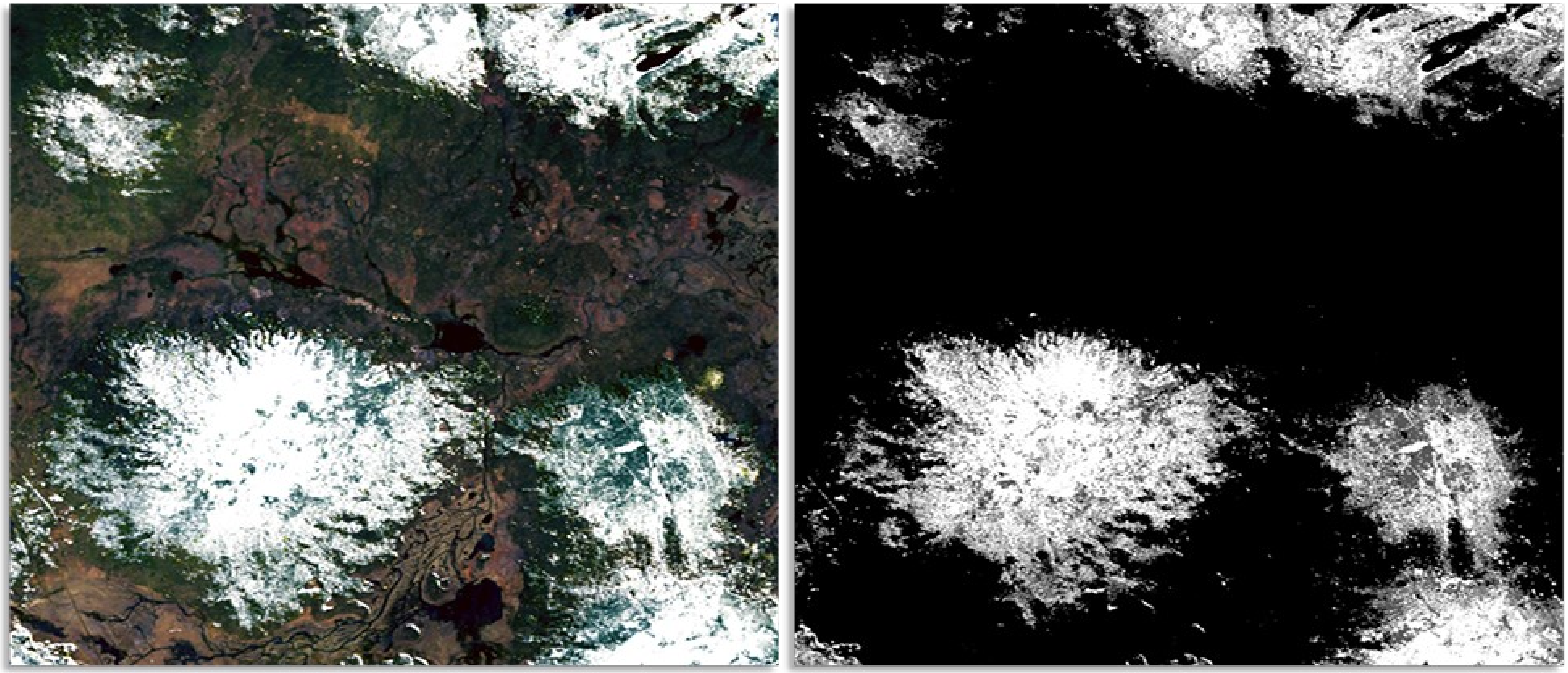

U.S. Geological Survey Landsat Fractional Snow Covered Area (fSCA)

Christopher Crawford[1] **and David Selkowitz**[2], U.S. Geological Survey Earth Resource Observation and Science Center[1] and Nevada Water Science Center[2]

Product algorithm and accuracy

- Landsat fSCA is generated using tiled Landsat Collection 1 U.S. Analysis Ready Data
- Landsat fSCA uses Collection 1 Level 1 calibrated Top-Of-Atmosphere (TOA) and Level 2 Surface Reflectance (SR) products to retrieve per-pixel fSCA and generate per-pixel quality assurance (QA)
- The Landsat fSCA retrieval is based on the Thematic Mapper Snow Cover Area and Grain Size (TMSCAG) algorithm (Painter et al. 2009, see below), incorporates an additional algorithm to adjust for underestimation of snow cover beneath forest canopy, and provides some additional QA information (i.e., revised cloud mask and water detection)
- Accuracy assessment using binary metrics for comparison with *in situ* observations from the Western US (n = 318,320) indicates overall accuracy of 0.94, with nearly equal rates of omission and commission errors
- Fractional accuracy assessment ongoing; limited in situ fSCA monitoring indicates RMSE of 0.20

Painter, T. H., Rittger, K., McKenzie, C., Slaughter, P., Davis, R. E., & Dozier, J., 2009. Retrieval of subpixel snow covered area, grain size, and albedo from MODIS. Remote Sensing of Environment, 113(4), 868-879.

Product highlights

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- The Landsat fSCA product spans 1984 to present and is produced for western United States and Alaska geographic domains on an operational basis
- Landsat fSCA product is accompanied by an Algorithm Description Document (ADD), user guide, and has a Digital Object Identifier (DOI)
- Known caveats and constraints have been quantified and the product is available on a non-discriminatory basis
- Known product users include academic universities and US land and water management agencies
- The USGS has released Landsat Collection 2 Level 1 and Level 2 data products as of December 2020, and planning is underway to transition Landsat fSCA product generation to Landsat Collection 2 U.S. Analysis Ready Data by the end of 2021
- The USGS is planning to generate fSCA products for Landsat 9 in 2022 and is currently evaluating and planning how to scale production to broader geographic domain

Product Summary Information Landsat C1 fSCA

snowpex

Product name	Landsat Collection 1 fSCA
Satellite & Sensor	Landsat 4/5 TM, Landsat 7 ETM+, Landsat 8 OLI
Retrieval Algorithm	Based on Thematic Mapper Snow Cover Area and Grain Size (TMSCAG) algorithm
Snow Parameter*	FSCG
Spatial Coverage	Western United States and Alaska
Map Projection	Albers Equal Area in WGS 1984 datum
Pixel spacing	30 meters
Temporal Coverage	1984 to present
Temporal Frequency	8 day (1993-1999 is only 16 day)
Accuracy Parameter **	Accuracy percent for SCEG, RMSE for FSCG
Accuracy Information ***	Accuracy values indicated are single global values
Webpage	[Landsat Fractional Snow Covered Area (usgs.gov)]
Contact Point:	Christopher Crawford, cjcrawford@usgs.gov
References	Selkowitz, D.J., Painter, T.H., Rittger, K.E., Schmidt, G., & Forster, R., 2017. "The USGS Landsat Snow Covered Area Products: Methods and Preliminary Validation." Automated Approaches for Snow and Ice Cover Monitoring Using Optical Remote Sensing. D. Selkowitz. Salt Lake City, UT: The University of Utah. pp. 76-119.