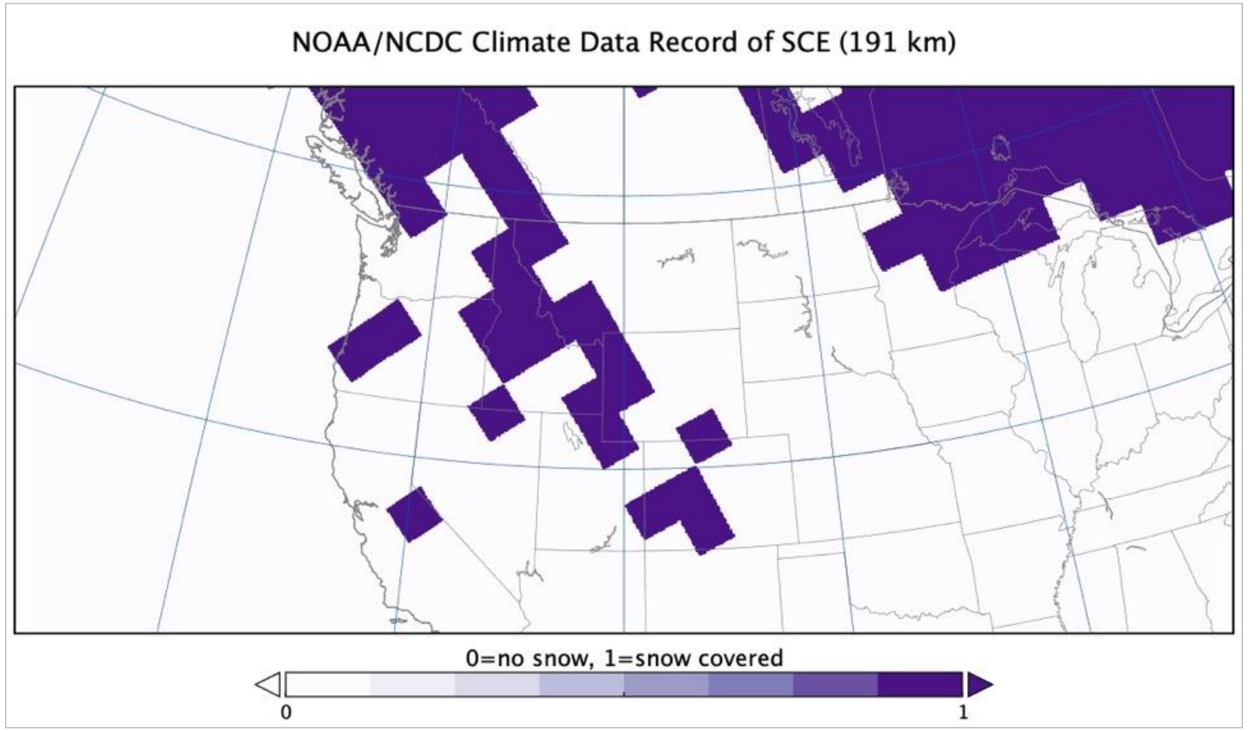
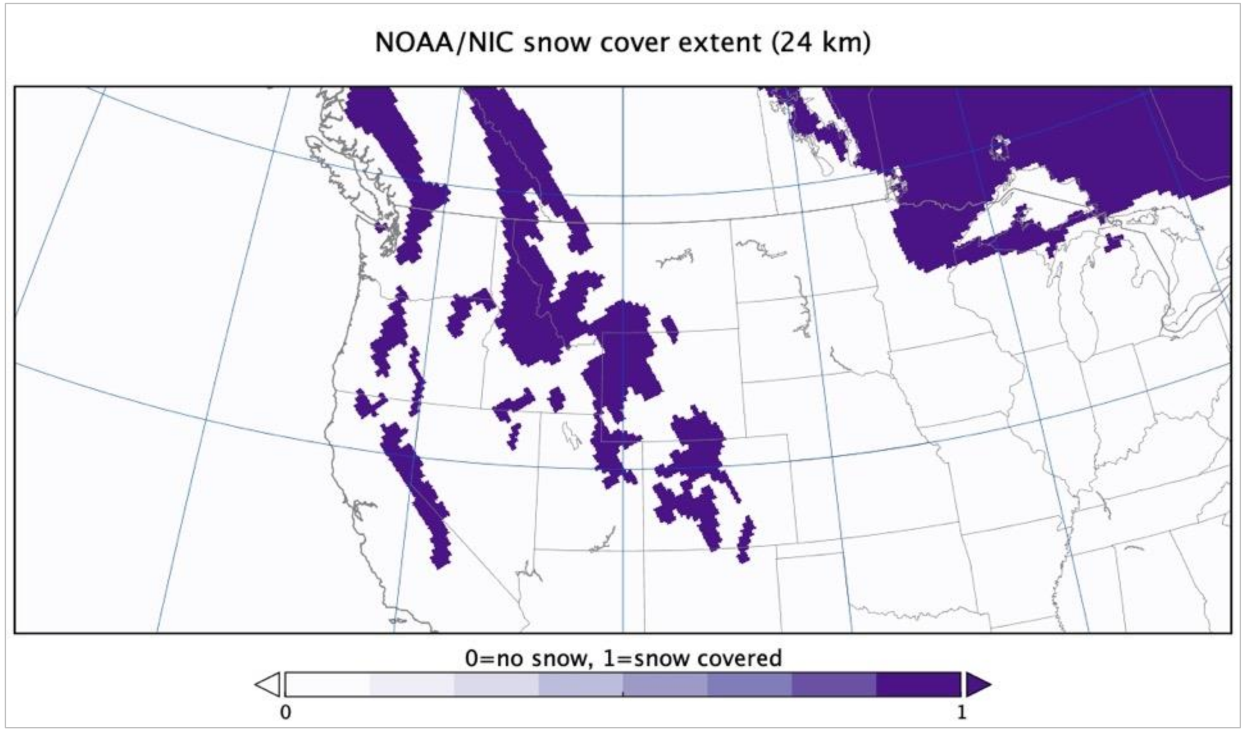
SNOW COVER EXTENT PRODUCTS

snowpex+

esa



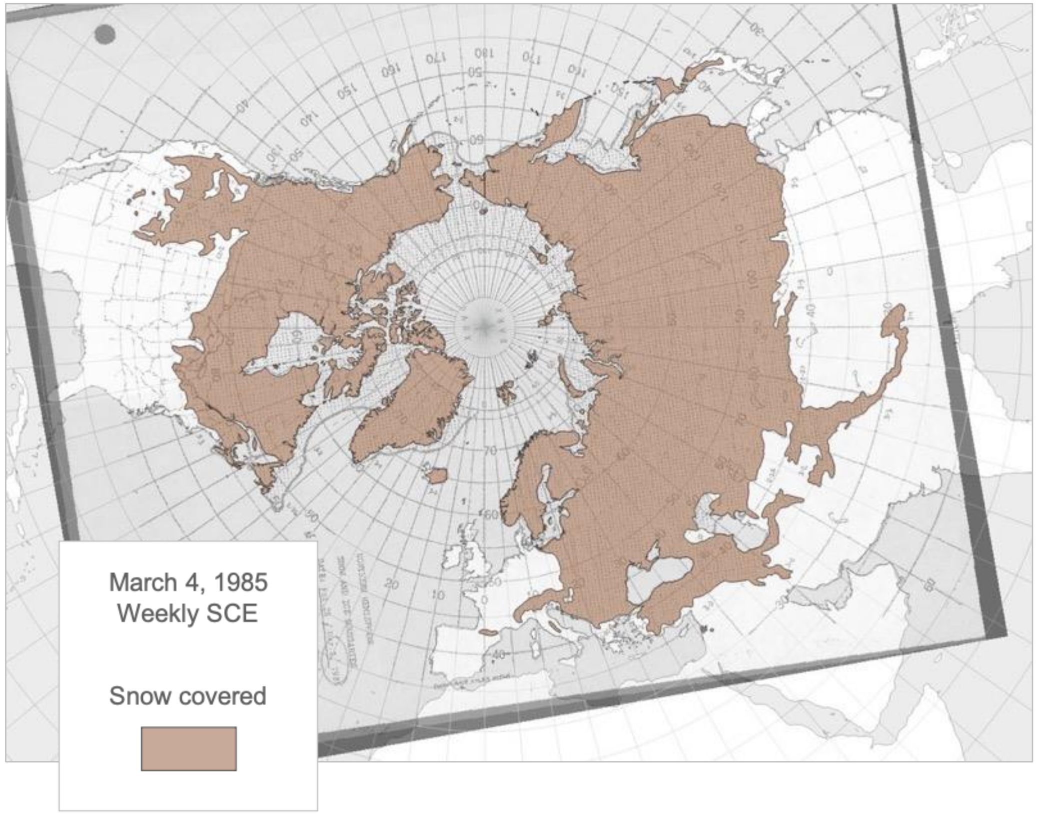


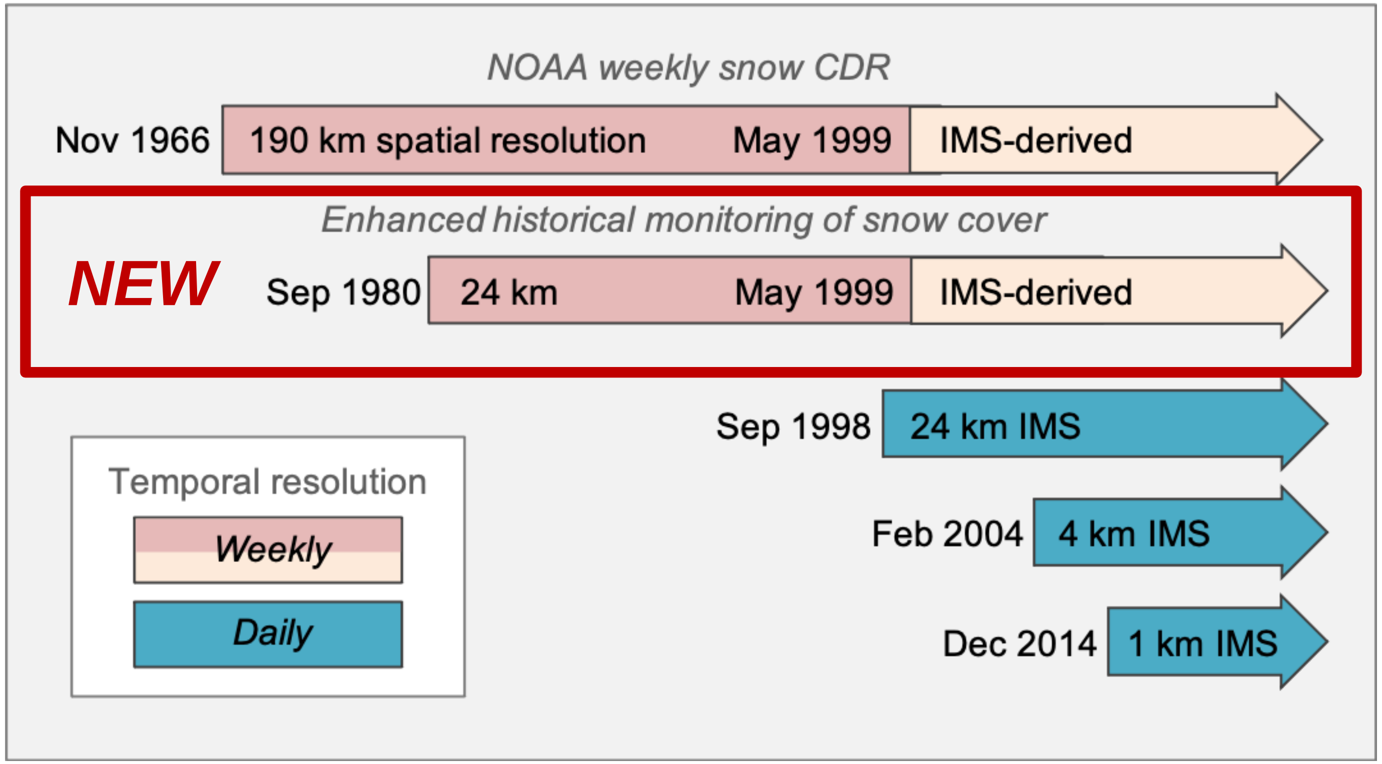
Rutgers Northern Hemisphere 24 km Weekly Snow Cover Extent, Sept 1980 onward

David Robinson, Rutgers University

Product input data

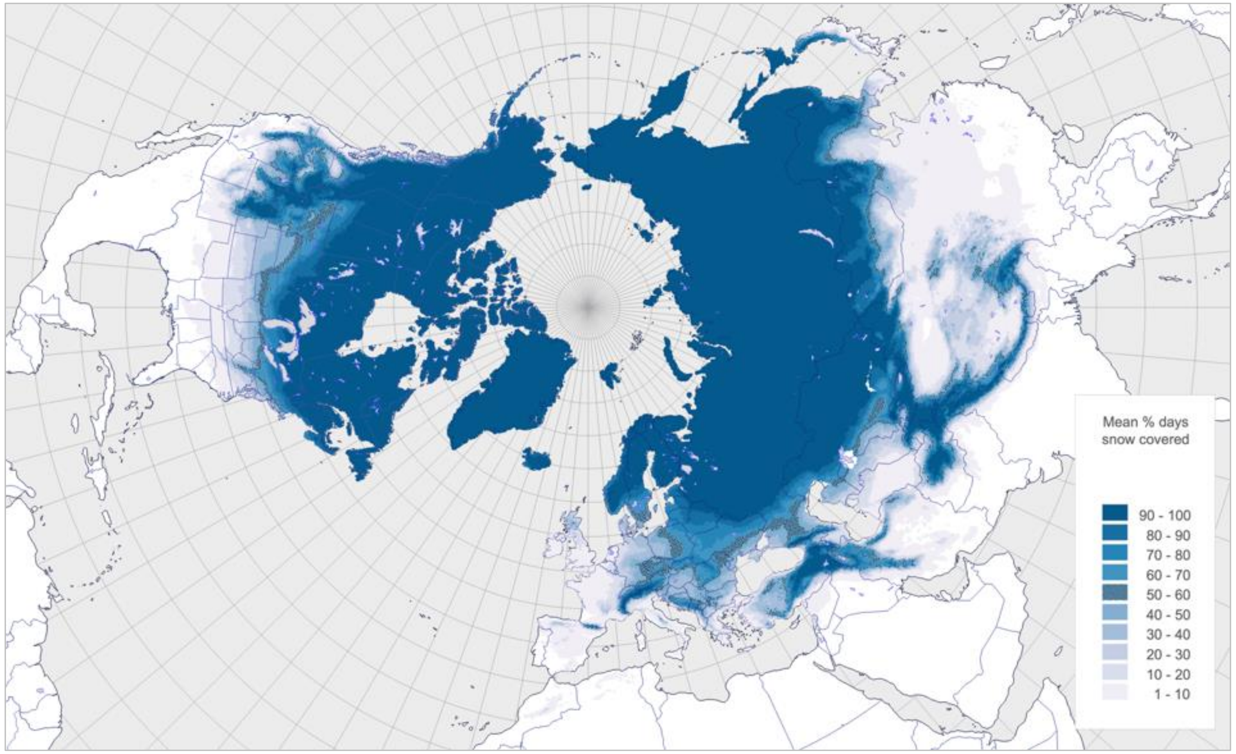
Re-digitization of 1981–1999 maps to generate a weekly product to 24 km resolution.



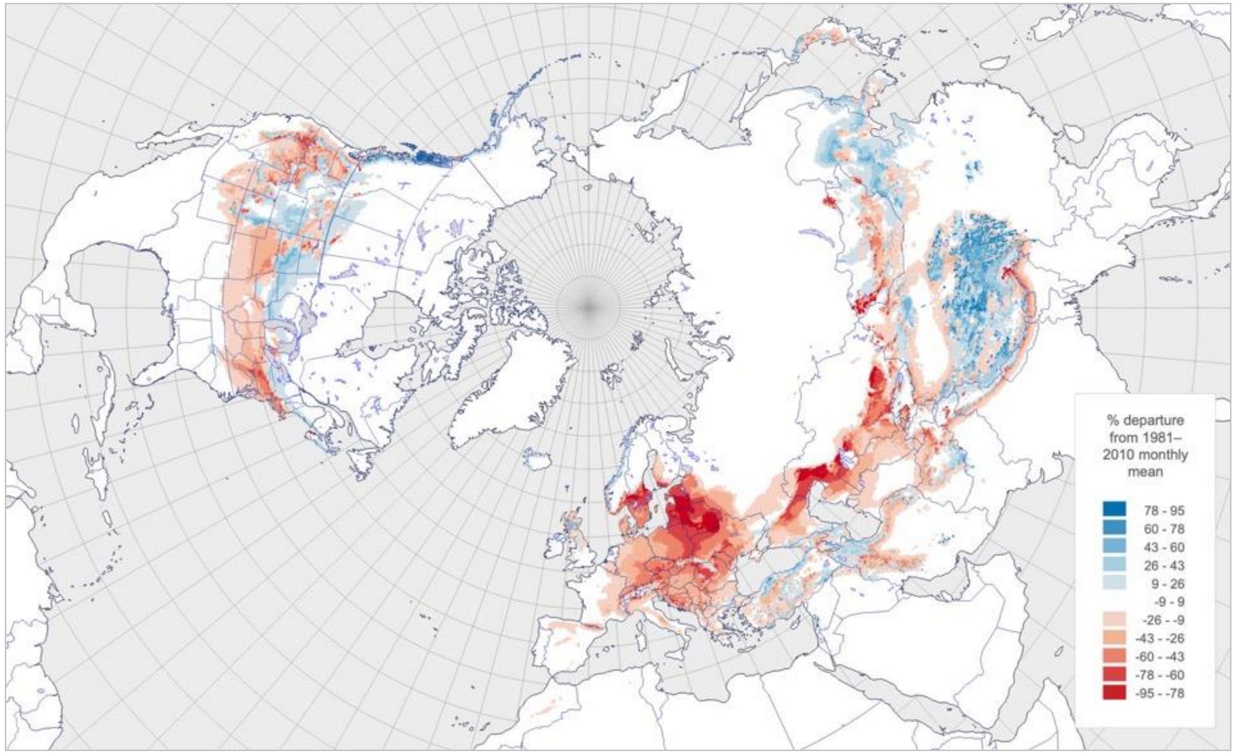


New product merged with IMS data to generate 1981–present 24 km weekly product.

Product highlights



Feb enhanced monthly 24 km mean SCE (1981–2010)



Feb 2020 monthly departure from normal (1981–2010)

NH snow cover extent (SCE) map product a work horse for over 50 years.

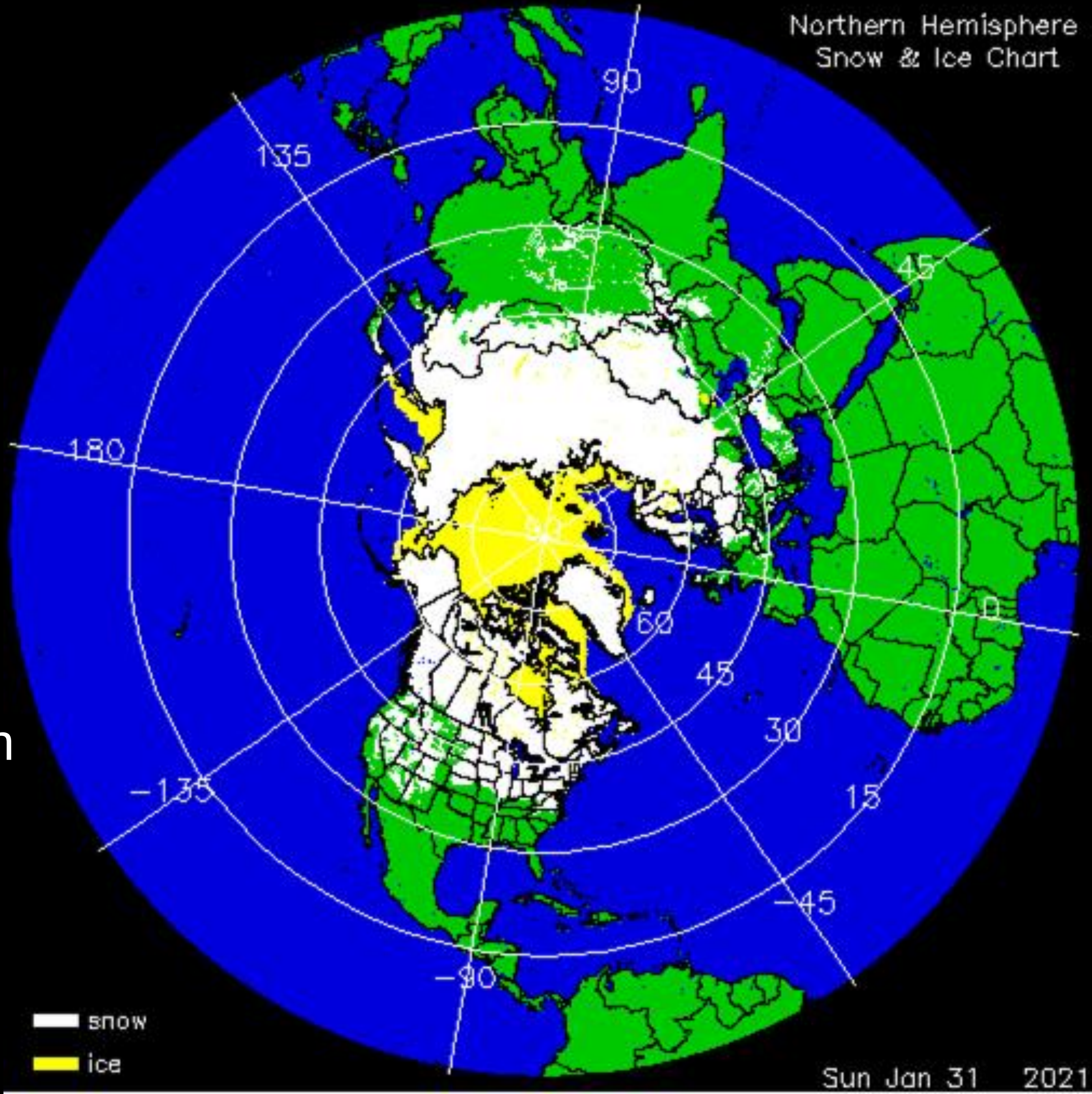
New SCE climatologies generated for multiple studies. 24 km climatology can be used to improve seasonal weather and water resource prediction.

Product Summary Information NSIDC G10035

Product name	NSIDC G10035, Rutgers Northern Hemisphere 24 km Weekly Snow Cover Extent, Sept 1980 onward
Satellite & Sensor	Interactive analyst SCE charting primarily from visible imagery
Retrieval Algorithm	Sept 1980–May 1999: NOAA weekly SCE charts, June 1999–present: Monday NIC IMS SCE
Snow Parameter*	SCE
Spatial Coverage	Northern Hemisphere land masses
Map Projection	Polar stereographic
Pixel spacing	Nominal 24 km (23.7 km @ standard parallel 60° N)
Temporal Coverage	Sept 1980–Aug 2020
Temporal Frequency	Weekly
Accuracy Parameter **	TBD
Accuracy Information ***	
Webpage	Snowcover.org
Contact Point:	David Robinson <david.robinson@rutgers.edu>
References	

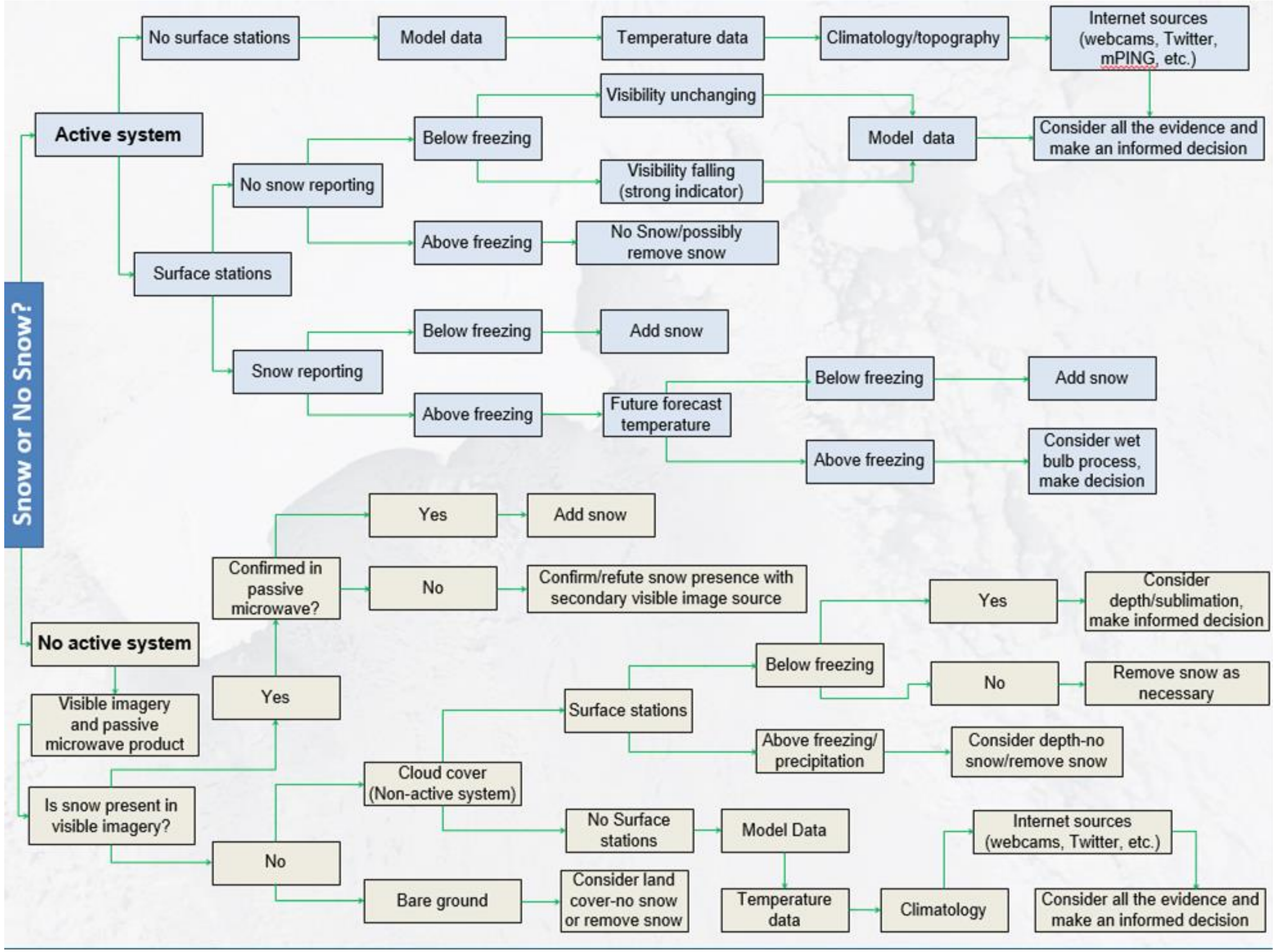
Interactive Multisensor Snow and Ice Mapping System (IMS)

Presenter: Walt Clark
U.S. National Ice Center
NOAA NWS OPC Ice Services Branch



Analysis Process and Accuracy

Sample Decision Tree for IMS Analyst



Accuracy

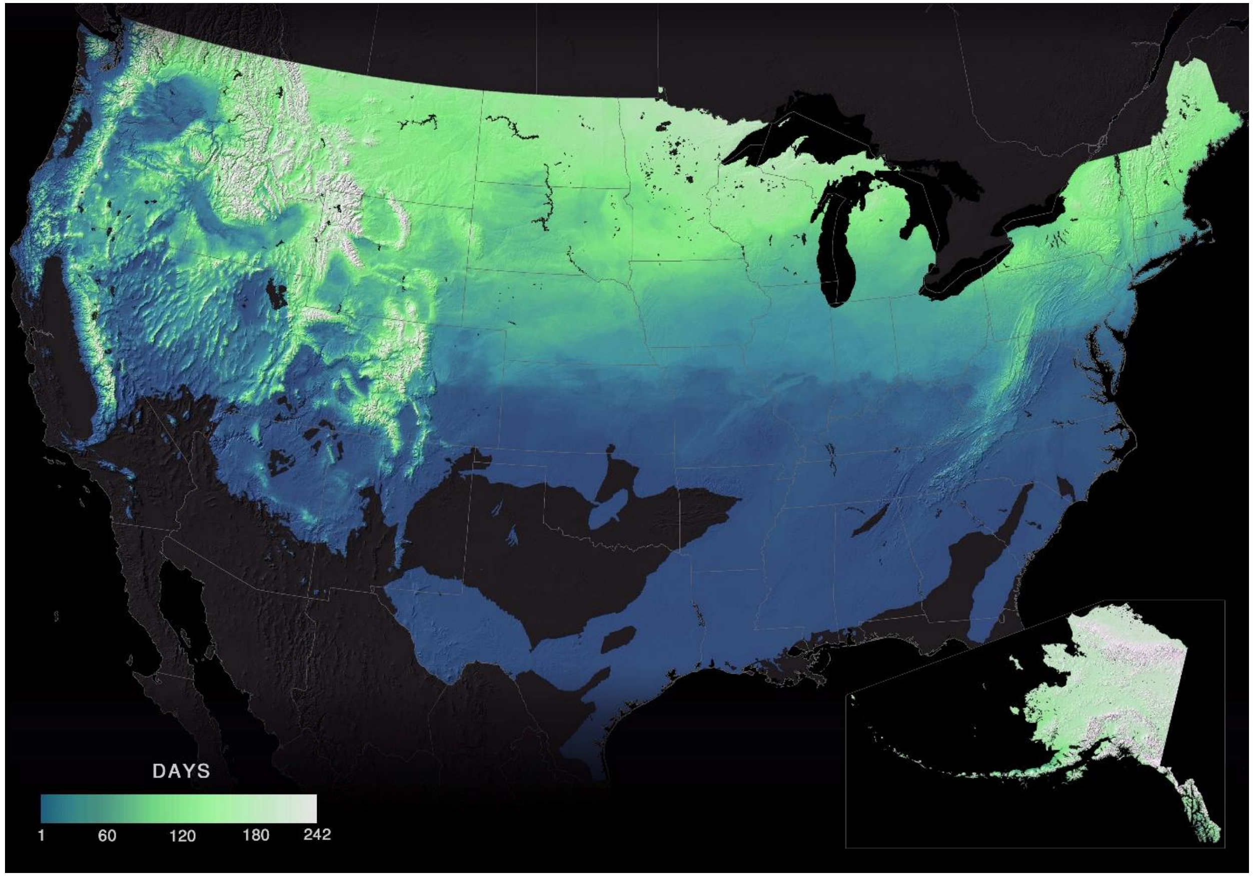
- Most studies suggest IMS snow cover has 85-90% agreement with all surface data and 95% agreement with stations reporting more than 2.5cm/1in
- ECMWF monitoring: www.ecmwf.int/en/forecasts/quality-our-forecasts/monitoring/ims-monitoring
- Chen C, T. Lakhankar, P Romanov,It S Helfrich, A. Powell, and R Khanbilvardi. 2012, Remote Sensing
- Brubaker, K. L., R. T. Pinker, E. Deviatova, 2005: Evaluation and Comparison of MODIS and IMS Snow-Cover Estimates for the Continental United States Using Station Data. J. Hydrometeor

Product highlights

- **Strengths:**
  - Operational mandate for numerical weather prediction.
    - Quick product availability.
  - Adaptable system can readily accept new imagery and improvements.
  - Cloud obscured retrievals made possible by trained analysis team utilizing multitude of satellite and ground based data.
  - Human input can quickly scan and rank data quality from multitude of satellite and ground observations.
  - Human ability to track active systems producing new snow

- **Weaknesses:**
  - Lacking southern hemisphere coverage.
  - Sparse in situ observations and latency of satellite data can degrade analysis
  - Complicated topography creates inhomogeneity that is difficult for analysts to predict.

Winter 2017-18 Number of Days with Snow on Ground from IMS

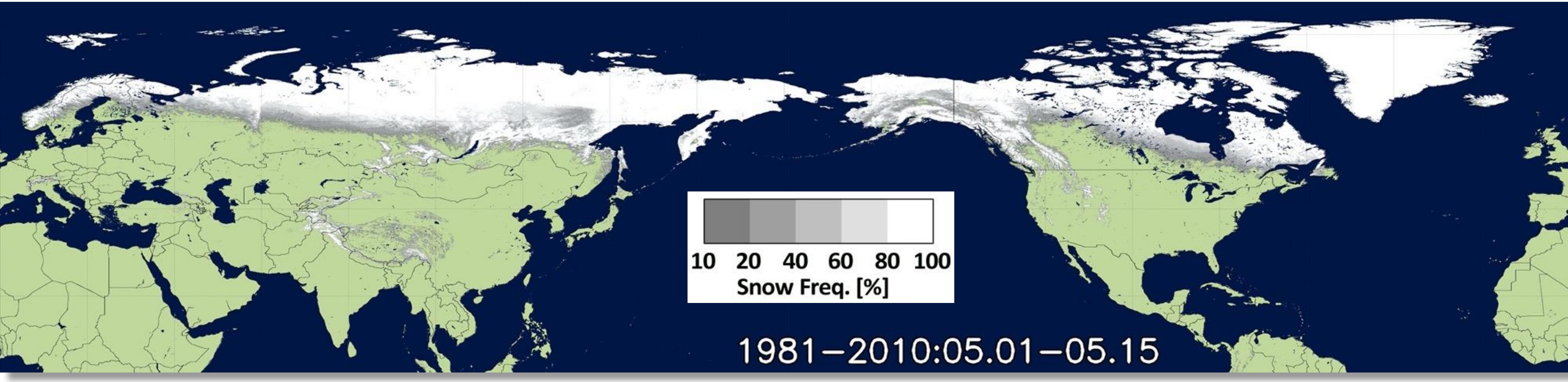


- **Archive length:** 1997 for 24km, 2004 for 4km, 2014 for 1km.
- **File Formats:** ASCII, ENVI DATs, GRIB2, GeoTIFF, quick look GIF.
- **Availability:** usicecenter.gov, NSIDC, and through NOAA’s Products Distribution Archive (PDA).

Product Summary Information IMS

Product name	IMS, Interactive Multisensor Snow and Ice Mapping System
Satellite & Sensor	Various GOES, Himawari, and Meteosat channels, AVHRR, VIIRS, AMSR, ASCAT, AMSU, SSMI, Radarsat, radar, ground station and other in situ observations.
Retrieval Algorithm	Synthesis of available imagery and data by trained analysis team.
Snow Parameter*	Binary snow cover. Also includes ice.
Spatial Coverage	Northern Hemisphere
Map Projection	IMS Polar Stereographic, WGS-84 with major axis 6378137m and minor axis 6356257m
Pixel spacing	24km, 4km, 1km
Temporal Coverage	Daily global coverage
Temporal Frequency	Daily, at 00Z, for N. Hemisphere. Twice daily,18Z and 00Z, for N. America.
Accuracy Parameter **	Days since last region last observed by analyst
Accuracy Information ***	0-200 day parameter recording last time analysts passed over a region
Webpage	https://usicecenter.gov/Products/ImsHome
Contact Point:	Walt Clark, walter.clark@noaa.gov
References	Algorithm Theoretical Basis Document (ATBD), email Walt for most current version

Climatology (1981-2010) of Northern Hemisphere SCE frequency for the 15-day periods of May 1–15.



JASMES Snow Cover Product (snwcfr)

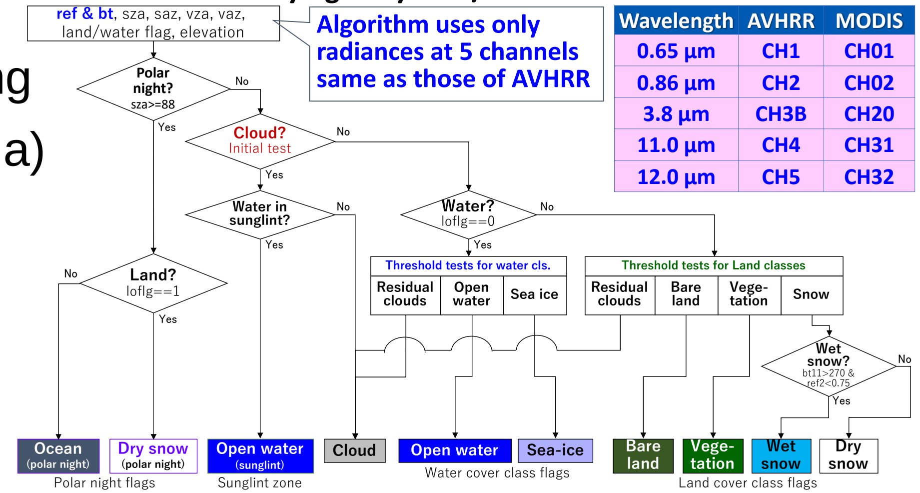
Masahiro Hori, University of Toyama

ArCS II Arctic Challenge for Sustainability II · JASMES · JAXA · University of Toyama

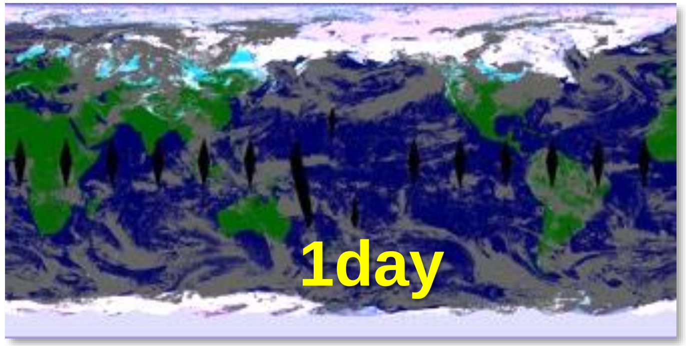
Product algorithm and accuracy

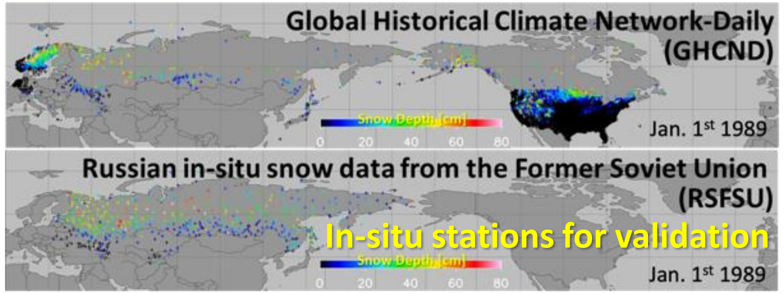
- Algorithm for snow detection: Threshold tests & Temporal filtering
- Input data: Radiance observed by optical sensors onboard polar-orbiting satellites (AVHRR on TIROS-N & NOAA series, MODIS on Terra & Aqua)
- Auxiliary data used for algorithm: ETOPO02 (DEM)
- Mask used in product: Water flag generated with GMT
- In-situ data for SCE validation: snow depth obtained from two sources;
  1) Global Historical Climate Network-Daily (GHCND)
  2) Russian in-situ snow data from the Former Soviet Union (RSFSU)
- Accuracy of snow cover detection: Not only one global (NH) accuracy values but also those evaluated every 4-degree interval grid cells were estimated using in-situ snow depth data over many weekly averaged products.

Flowchart for classifying daily land/ocean classes



Wavelength	AVHRR	MODIS
0.65 µm	CH1	CH01
0.86 µm	CH2	CH02
3.8 µm	CH3B	CH20
11.0 µm	CH4	CH31
12.0 µm	CH5	CH32





Overall accuracy (OA) $= (n_{11} + n_{22}) / n$

User's accuracy (UA) $= n_{11} / (n_{11} + n_{12})$

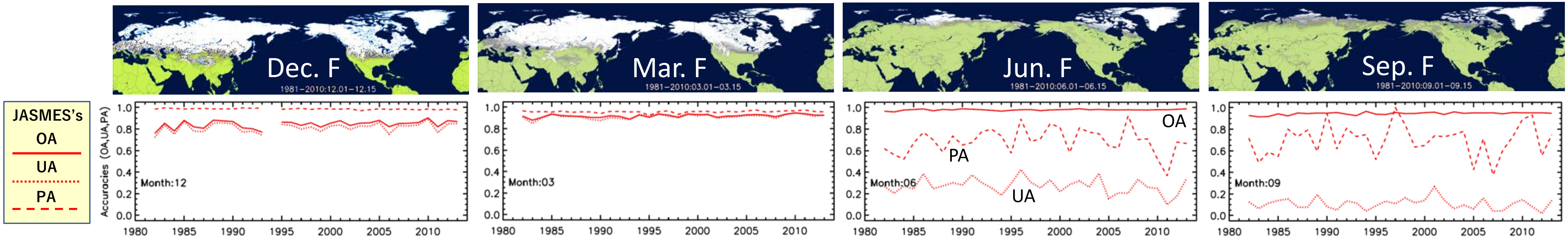
Producer's accuracy (PA) $= n_{11} / (n_{11} + n_{21})$

Class		Reference: In-situ station		
		Snow	Non-Snow	Total
Satellite	Snow	n_{11}	n_{12}	$n_{1.}$
	Non-Snow	n_{21}	n_{22}	$n_{2.}$
	Total	$n_{.1}$	$n_{.2}$	n

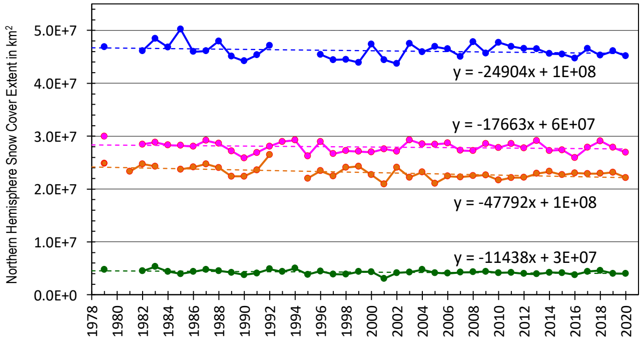
Error matrix for accuracy estimation

Product highlights

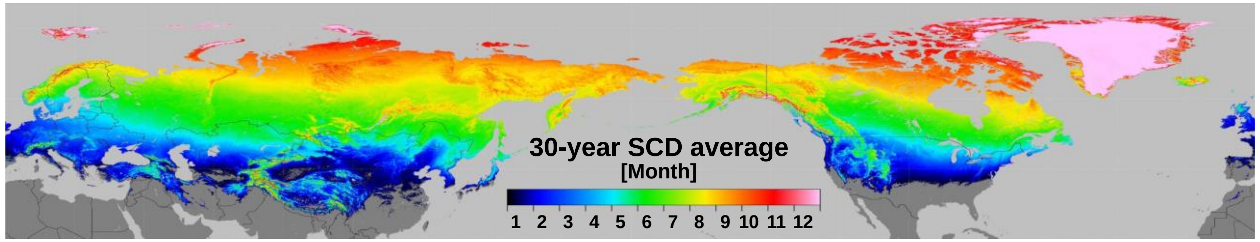
Snow cover freq. map and temporal variations of SC detection accuracies for four months (Dec., Mar., Jun., Sep.)

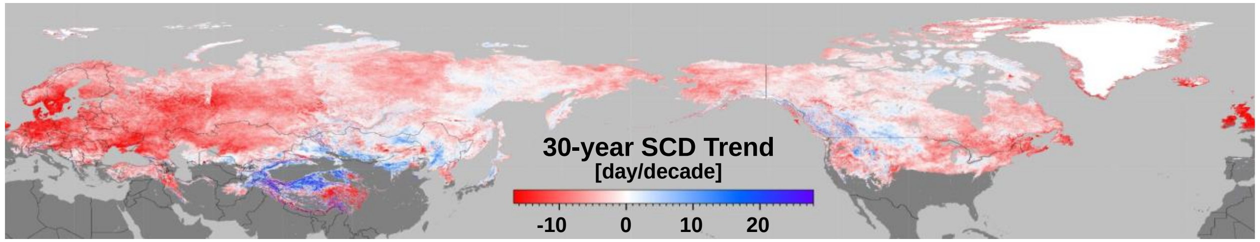


- OAs are always high (0.82-0.99). UAs and PAs are high in winter & spring and tend to get lower in summer and autumn. The difference between PA and UA get larger in autumn, suggesting SCEs tend to be overestimated (commission error > omission).
- The accuracies (OA, UA, PA) are temporally stable (no significant trends) during the past 30 years.
- SCE in NH derived from the JASMES product exhibits negative trends in all seasons.



42-Year Variation of Seasonal SCEs in NH (1979-2020)





- 30-year average (1982–2013) and trend of Snow Cover Duration (SCD) are derived from the JASMES product.
- SCD is getting shorter in Western Eurasia, while the signals of Eastern Eurasia and North America are weak.

Product Summary Information (1/3) SNWCFR_JXAM5_M5C

Product name	JASMES SNWCFR, JASMES Snow Cover and Cloudiness Product
Satellite & Sensor	AVHRR onboard TIROS-N, NOAA series, MODIS onboard Terra and Aqua (snwcfr_JXAM5_M5C)
Retrieval Algorithm	JXAM5: Threshold tests & temporal filtering using the same five spectral channels
Snow Parameter*	SCEV (Snow cover extent binary; in forests: on top of canopy (viewable snow - SCEV))
Spatial Coverage	Global
Map Projection	Equirectangular (lat/lon) projection
Pixel spacing	0.05 degree (1D, 1W, HM) (An optional product with the pixel spacing of 0.25 degree (HM temporal frequency) is also available.)
Temporal Coverage	November 1978 - the present (except for the periods of Feb.1980-Jun1981 & Sep.1994-Jan.1995)
Temporal Frequency	1-day (1D), 1-week (1W), half-month (HM)
Accuracy Parameter **	Overall, User’s and Producer’s accuracies evaluated based on the error matrix of sample counts.
Accuracy Information ***	One global value derived from validation data over many weekly averaged products. Accuracies are also evaluated every 4-degree interval equal-area lat-lon grid cells. See Hori et al. (2017)
Webpage	https://kuroshio.eorc.jaxa.jp/JASMES/index.html
Contact Point:	Masahiro HORI, mhori@sus.u-toyama.ac.jp
References	Hori et al., Remote Sens. Environ., 191, 402-418, 2017. https://doi.org/10.1016/j.rse.2017.01.023

Product Summary Information (2/3) SNWCFR_JXAM5_A5C

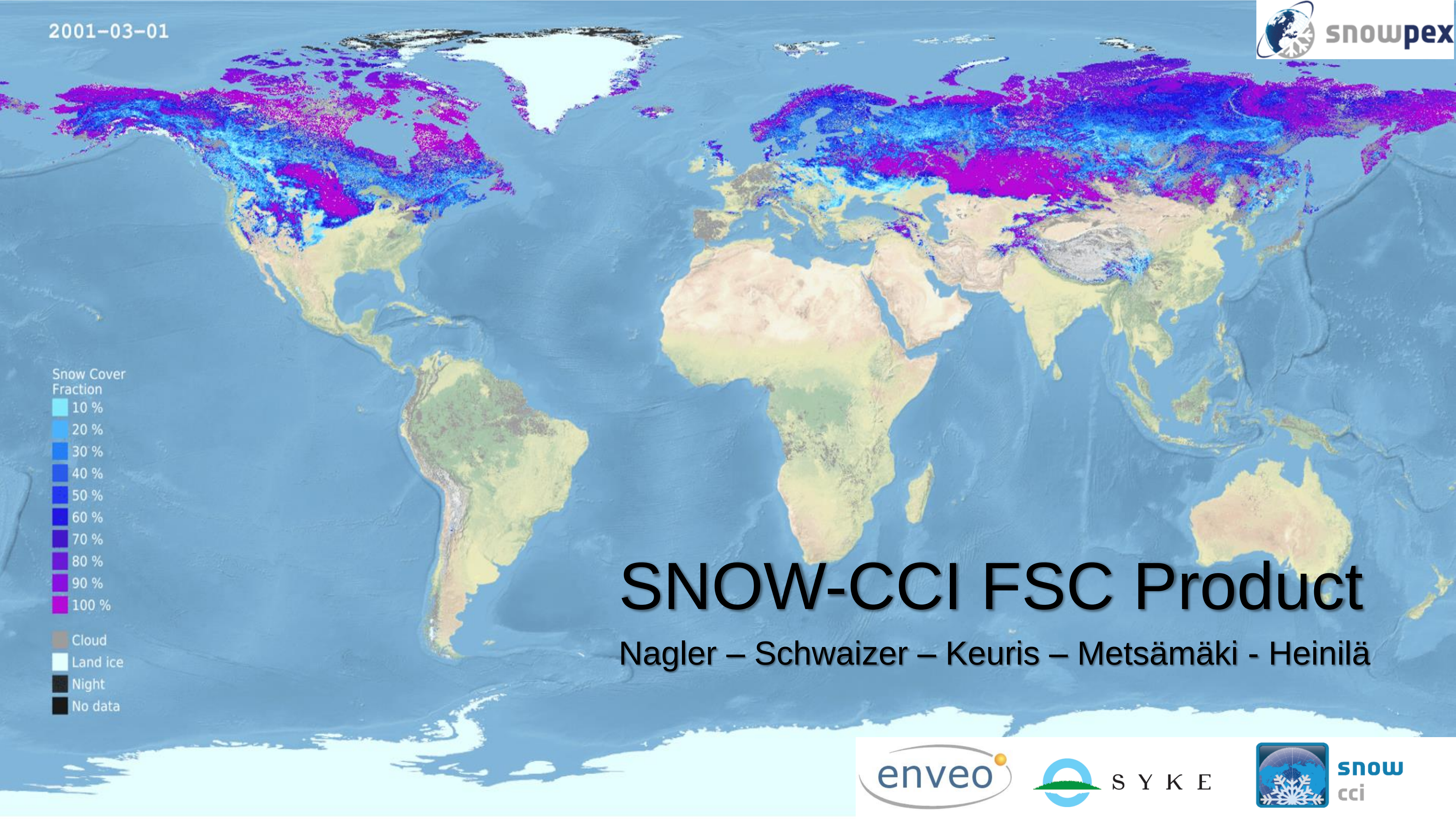
Product name	JASMES SNWCFR, JASMES Snow Cover and Cloudiness Product
Satellite & Sensor	AVHRR onboard TIROS-N, NOAA series, MODIS onboard ~~Terra and~~ Aqua (snwcfr_JXAM5_A5C)
Retrieval Algorithm	JXAM5: Threshold tests & temporal filtering using the same five spectral channels
Snow Parameter*	SCEV (Snow cover extent binary; in forests: on top of canopy (viewable snow - SCEV))
Spatial Coverage	Global
Map Projection	Equirectangular (lat/lon) projection
Pixel spacing	0.05 degree (1D, 1W, HM) (An optional product with the pixel spacing of 0.25 degree (HM temporal frequency) is also available.)
Temporal Coverage	November 1978 - the present (except for the periods of Feb.1980-Jun1981 & Sep.1994-Jan.1995)
Temporal Frequency	1-day (1D), 1-week (1W), half-month (HM)
Accuracy Parameter **	Overall, User's and Producer's accuracies evaluated based on the error matrix of sample counts.
Accuracy Information ***	One global value derived from validation data over many weekly averaged products. The accuracies of "JXAM5_A5C" are still under investigation but not so different from those of "M5C".
Webpage	https://kuroshio.eorc.jaxa.jp/JASMES/index.html
Contact Point:	Masahiro HORI, mhori@sus.u-toyama.ac.jp
References	The algorithm itself is the same as that of snwcfr_JXAM5_M5C (Hori et al. 2017).

Product Summary Information (3/3) SNWCFR_JXM10

Product name	JASMES SNWCFR, JASMES Snow Cover and Cloudiness Product
Satellite & Sensor	MODIS onboard Terra and Aqua (snwcfr_JXM10)
Retrieval Algorithm	JXM10: Threshold tests & temporal filtering using ten spectral channels of MODIS
Snow Parameter*	SCEV (Snow cover extent binary; in forests: on top of canopy (viewable snow - SCEV))
Spatial Coverage	Global
Map Projection	Equirectangular (lat/lon) projection
Pixel spacing	0.05 degree (1D, 1W, HM) (An optional product with the pixel spacing of 0.25 degree (HM temporal frequency) is also available.)
Temporal Coverage	February 2000 - the present
Temporal Frequency	1-day (1D), 1-week (1W), half-month (HM)
Accuracy Parameter **	Overall, User's and Producer's accuracies evaluated based on the error matrix of sample counts.
Accuracy Information ***	One global value derived from validation data over many weekly averaged products. The evaluated accuracies of "JXM10" are better than those of "JXAM5_M5C" (not published).
Webpage	https://kuroshio.eorc.jaxa.jp/JASMES/index.html
Contact Point:	Masahiro HORI, mhori@sus.u-toyama.ac.jp
References	(ReadMe) https://kuroshio.eorc.jaxa.jp/JASMES/docs/CSF_gl_data.html

SNOW-CCI FSC Product

Nagler – Schwaizer – Keuris – Metsämäki - Heinilä



snowpex

enveo

SYKE

snow cci

Product algorithm and accuracy

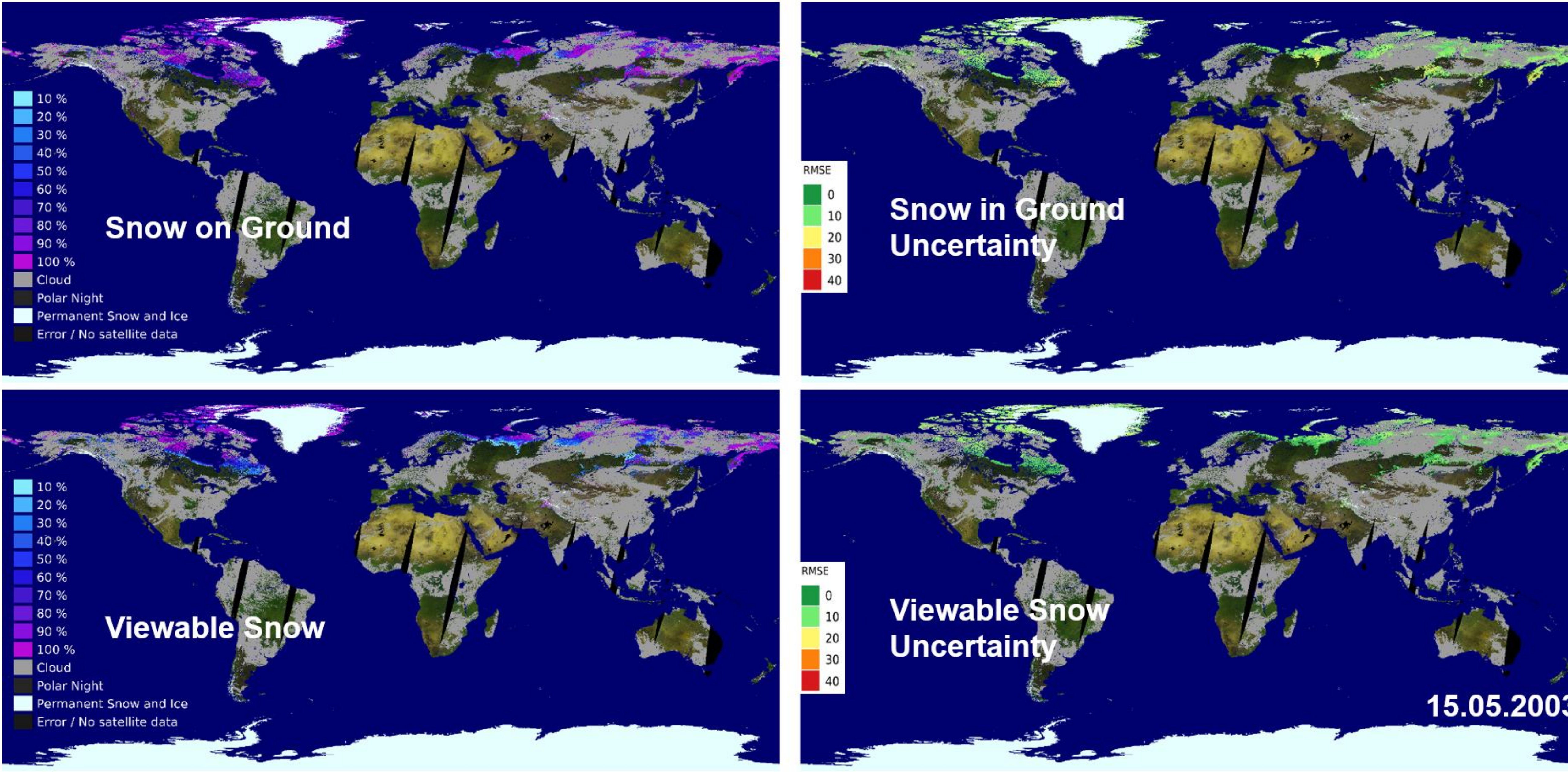
Multi-step algorithm for generating a consistent set of Viewable FSC and Canopy-Corrected FSC (snow on Ground) product including per-pixel uncertainty layer

- **Step 1: Cloud screening**
    - SCDA Version 3 (improved based on SCDA V2, Metsämäki et al. 2015)
    - Additional criterion on brightness temperature in tropics and subtropical regions
- **Step 2: Pre-classification of snow free areas**
    - NDSI threshold dependent on latitude, elevation surface classes and season
    - Threshold on BT
- **Step 3: Estimation of FSC**
    - FSC-V/G algorithm extending SCAmod concept (Metsämäki et al. 2015)
    - global maps of ground reflectance and forest reflectance
    - improved global canopy correction layer

Uncertainty estimation

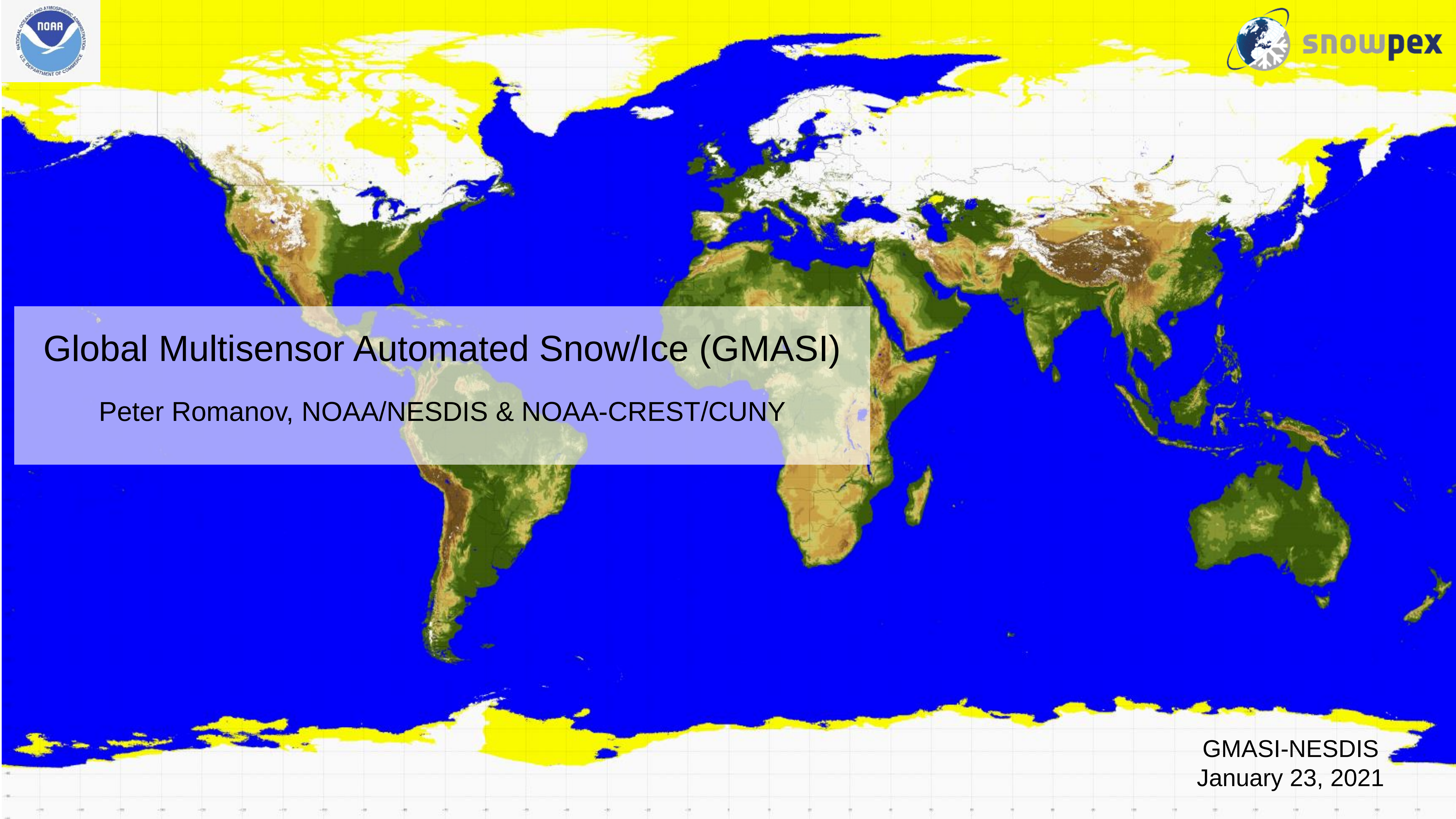
- RMSE derived by error propagation of parameters in retrieval algorithms
- calculated pixel by pixel
- typical product accuracy for open areas: unbiased RMSE ~14%, Bias ~ -6%, R ~ 0.95

Product highlights



Product Summary Information   Snow-CCI FSC 1KM

Product name	**Snow- CCI FSC 1KM MODIS / SENTINEL-3**
Satellite & Sensor	MODIS, continued SENTINEL-3 SLSTR
Retrieval Algorithm	Extended SCAmod (variable ground reflectance data)
Snow Parameter*	Consistent set of FSCV and FSCG
Spatial Coverage	global (without Antarctica)
Map Projection	Latitude-Longitude Grid
Pixel spacing	0.01 deg. (ca 1 km)
Temporal Coverage	2000 – 2019 (2020)
Temporal Frequency	Daily
Accuracy Parameter **	RMSE
Accuracy Information ***	per pixel, layer attached for every daily products
Webpage	http://snow-cci.enveo.at/ , data available at https://climate.esa.int/en/odp/#/dashboard
Contact Point:	thomas.nagler@enveo.at



Global Multisensor Automated Snow/Ice (GMASI)

Peter Romanov, NOAA/NESDIS & NOAA-CREST/CUNY

GMASI-NESDIS
January 23, 2021

Product algorithm and accuracy - GMASI

Features: Binary snow/ice, global, daily, no gaps in area coverage, 4 km (0.04^0) resolution

Algorithm: Synergy of snow retrievals from vis/IR and microwave.
Recurrent gap-filling

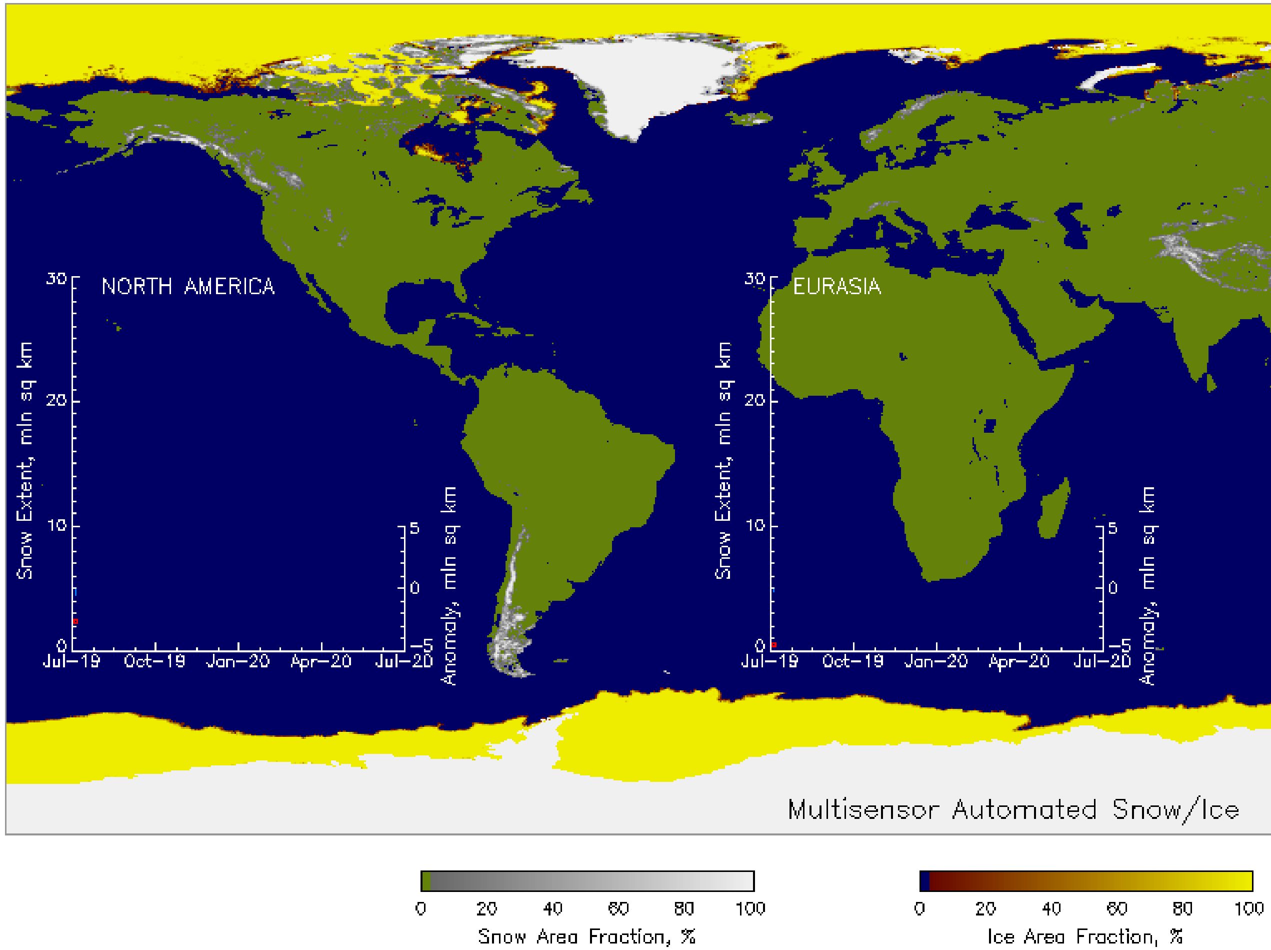
Satellite Input: AVHRR (NOAA, METOP) + all SSMI & SSMIS DMSP

Auxiliary: Elevation, land mask, vegetation cover type, climatology (LST, snow cover, SST)

Accuracy: ~ 93% agreement to IMS, ~ 90% agreement to in situ, (yearly-mean, snow/no-snow)
~ 4% mean difference with IMS on daily continental-scale snow area extent

Snow mapping accuracy varies with season, region, topography, vegetation cover
Accuracy depends on particular validation approach

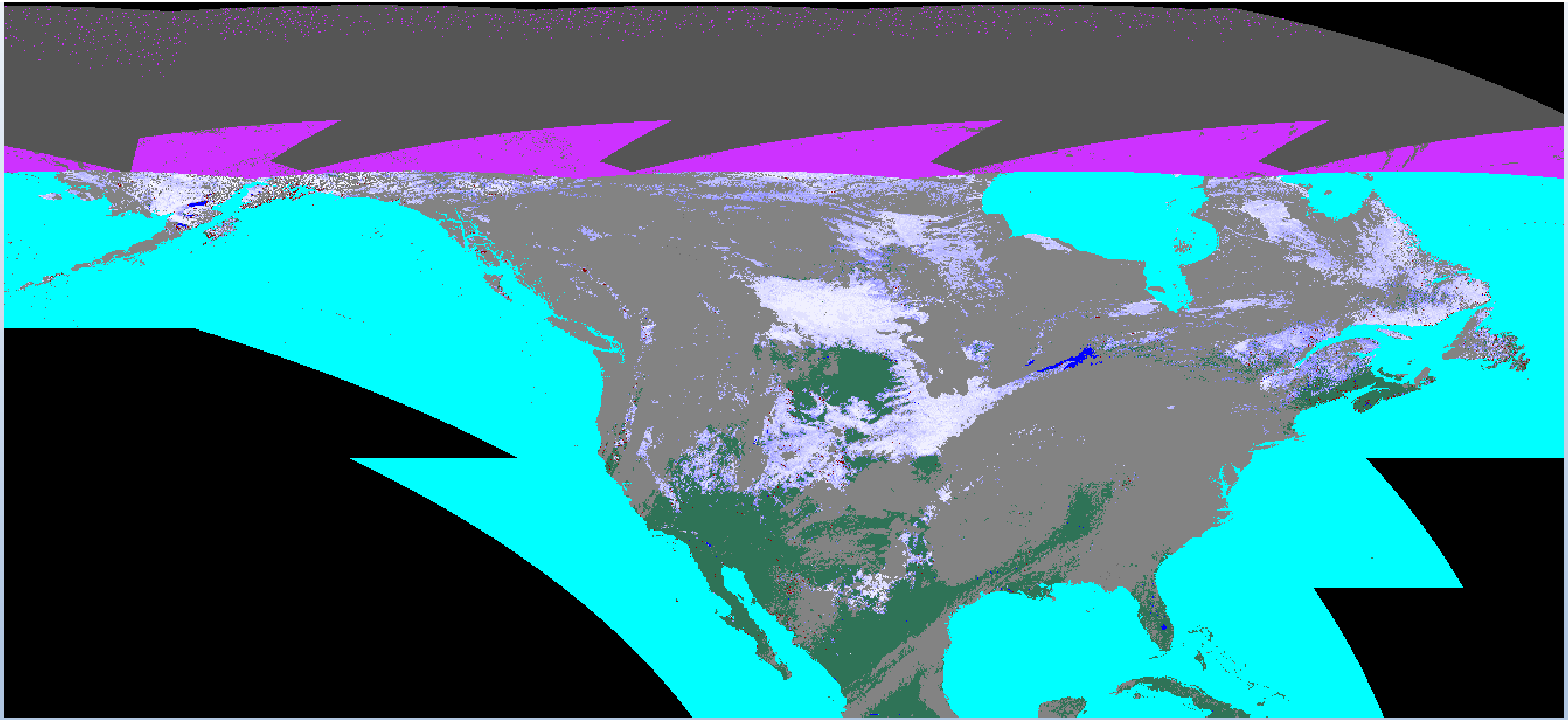
Product highlights - GMASI



- Operational at NESDIS since 2006, operational application: IMS, JPSS, GPM, IceSAT, EMC, etc.
- Processed back to mid-1987 (33-year daily time series available)
- Snow fraction since 1987 (supplemental product, AVHRR-based, viewable, 4 km)
- 2 km version GMASI: delivered to Ops, to become operational in mid-2021

Product Summary Information GMASI

Product name	GMASI, Global Multisensor Automated Snow/Ice Maps
Satellite & Sensor	AVHRR (METOP/NOAA), SSMI/SSMIS DMSP F8…19
Retrieval Algorithm	Synergy of snow retrievals in vis/IR and microwave
Snow Parameter*	Snow extent (binary snow map)
Spatial Coverage	Global, spatially continuous (no gaps)
Map Projection	Geographical (lat-lon)
Pixel spacing	0.04^0 x 0.04^0
Temporal Coverage	Year-round, 1987- ongoing,
Temporal Frequency	Daily
Accuracy Parameter **	Fraction of correct snow/no-snow identifications
Accuracy Information ***	Daily estimates, all Northern Hemisphere, compared to IMS and in situ
Webpage	Operational: https://satepsanone.nesdis.noaa.gov/northern_hemisphere_multisensor.html Research, quasi-ops: https://www.star.nesdis.noaa.gov/smcd/emb/snow/HTML/snow.htm
Contact Point:	Peter Romanov, Peter.Romanov@noaa.gov
References	Romanov P. (2017) Global multisensor automated satellite-based snow and ice mapping system (GMASI) for cryosphere monitoring. Remote Sensing of Environment, 196, 42-55



MODIS and VIIRS Snow Cover Products

George Riggs, SSAI

Product algorithm and accuracy

Snow retrieval algorithm applied at Level-2

- NDSI snow cover detection
- Data screens applied to prevent uncertain snow detections and set flags for quality assessment, flags stored in the products
- The MODIS land water mask used for both MODIS and VIIRS
- Cloud masking is done using the MODIS and VIIRS cloud mask products. Results of data screens and cloud mask flags are stored in the products

Level-3 products are produced by projecting the Level-2 products to the Sinusoidal projection. Approximately 50 m geolocation uncertainty possible

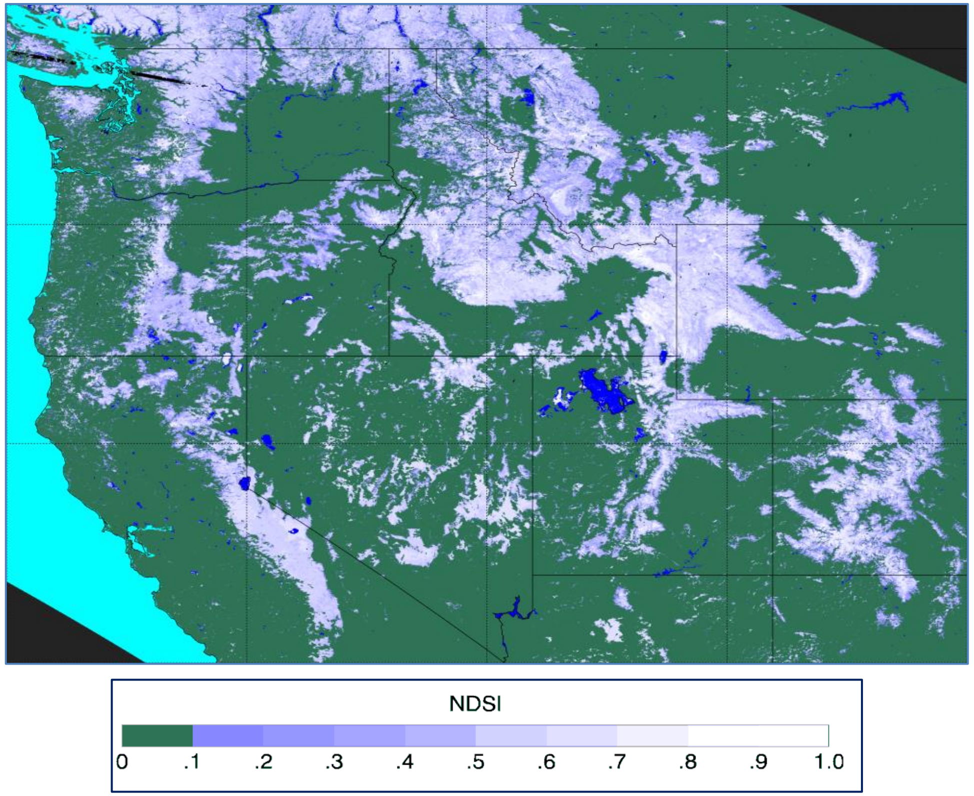
Snow cover accuracy is estimated to be approximately 90% based on validation and results reported in the literature. The algorithm quality flags stored in the product can be used for assessing accuracy.

Cloud-gap-filled (CGF) algorithm input is current day L3 product and previous day CGF product, retains previous day cloud free observation if current day observation is cloud. Accuracy is influenced by cloud persistence.

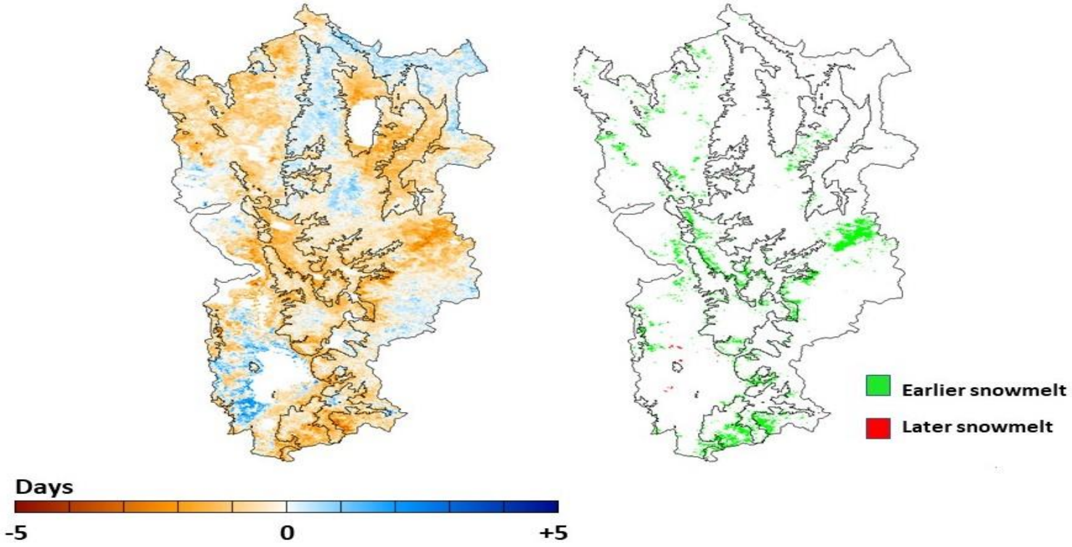
The MOD10A1F and VNP10A1F CGF products have recently been released.

Product highlights

Cloud-gap-filled MODIS and VIIRS snow cover products MOD10A1F V61 and VNP101F V1 are available at the NSIDC DAAC



19 March 2012



The role of declining snow cover in the desiccation of the Great Salt Lake,Utah, using MODIS data

Dorothy K. Hall, Donal S. O'Leary III, Nicolo E. DiGirolamod, Woodruff Millere and Do Hyuk Kanga

Remote Sensing of Environment 252 (2021) 112106
https://doi.org/10.1016/j.rse.2020.112106

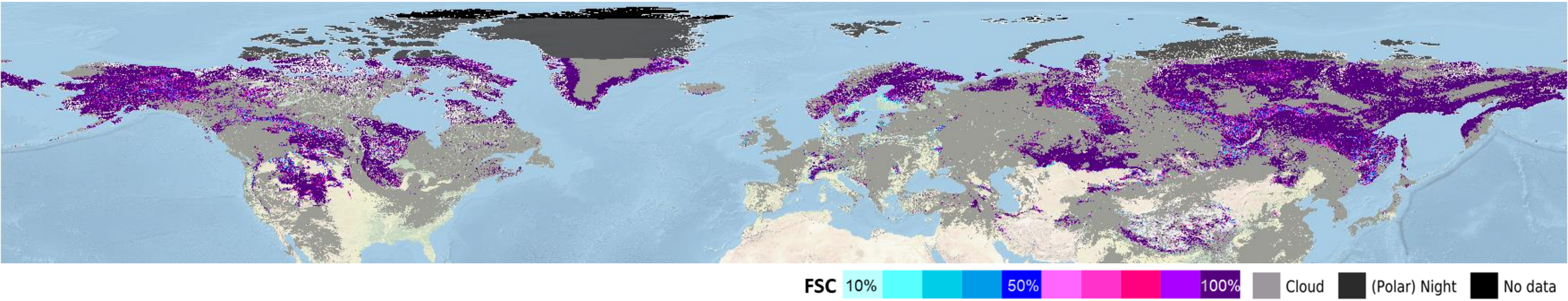
Fig. 6. a) Trends in snowmelt timing in days/yr for the Great Salt Lake basin from WY 2001 to 2018, using a modification of the snowmelt-timing map product of O'Leary III et al. (2017). The orange colors indicate earlier snowmelt, while the blue colors represent later snowmelt. b) Pixels for which the trends are statistically significant (α = 0.05) as shown with red indicate a trend toward earlier snowmelt, and the few (only 16) green pixels in the southwestern part of the basin, indicate a trend toward later snowmelt. The black line delineates the lower (< 2000 m) and higher (≥2000 m) elevations in both a) and b) as seen in Fig. 1.

Product Summary Information MOD10A1

Product name	MOD10A1, MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid, Version 6
Satellite & Sensor	Terra, MODIS
Retrieval Algorithm	NDSI snow cover detection
Snow Parameter*	SCE
Spatial Coverage	Global, daylight
Map Projection	Sinusoidal
Pixel spacing	500 m
Temporal Coverage	24 February 2000 to present
Temporal Frequency	daily
Accuracy Parameter **	Quality flag
Accuracy Information ***	Quality flags data layer
Webpage	https://nsidc.org/data/MOD10A1/versions/6
Contact Point:	George Riggs, george.a.riggs@nasa.gov
References	Hall, D. K. and G. A. Riggs. 2016. *MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid, Version 6*. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/MODIS/MOD10A1.006.

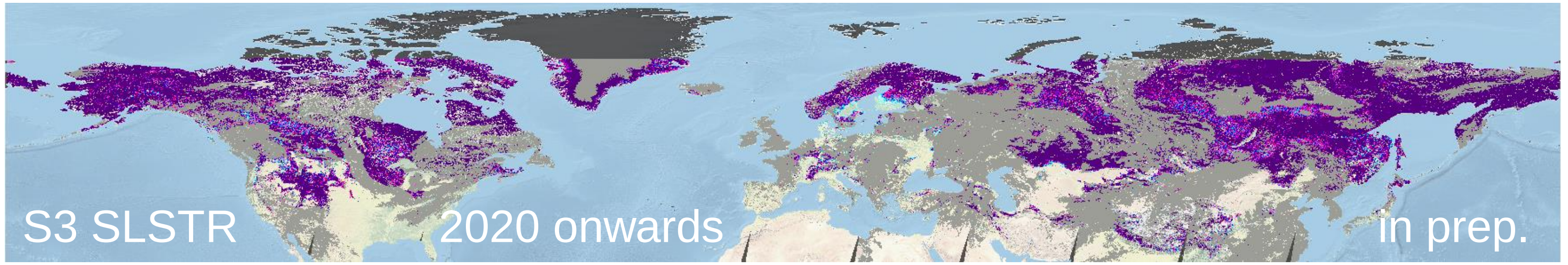
Product Summary Information VNP10A1

Product name	VNP10A1, VIIRS/NPP Snow Cover Daily L3 Global 375m SIN Grid, Version 1
Satellite & Sensor	Suomi-NPP, VIIRS
Retrieval Algorithm	NDSI snow cover detection
Snow Parameter*	SCE
Spatial Coverage	Global, daylight
Map Projection	Sinusoidal
Pixel spacing	375 m
Temporal Coverage	19 January 2012 to present
Temporal Frequency	daily
Accuracy Parameter **	Quality flag
Accuracy Information ***	Quality flags data layer
Webpage	https://nsidc.org/data/VNP10A1/versions/1
Contact Point:	George Riggs, george.a.riggs@nasa.gov
References	Riggs, G. A., D. K. Hall, and M. O. Román. 2019. *VIIRS/NPP Snow Cover Daily L3 Global 375m SIN Grid, Version 1*. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/VIIRS/VNP10A1.001.



Northern Hemisphere Snow Cover Extent of the Copernicus Global Land Monitoring Service

Gabriele Schwaizer, Thomas Nagler, Lars Keuris (ENVEO)
Sari Metsämäki (SYKE), Kari Luojus (FMI)



Snow retrieval and accuracy

Daily Fractional Snow Cover Extent for the Northern Hemisphere

Input data: Suomi-NPP VIIRS L1C data /
Sentinel-3 SLSTR L1C data (in prep.)

Snow retrieval approach:

- Cloud screening: SCDA v2.0 (Metsämäki et al., 2005)
- Pre-classification of snow free areas: NDSI & BT thresholds
- FSCG retrieval: SCAmod (Metsämäki et al., 2012)
  - Transmissivity map for Northern Hemisphere
  - Water mask from ESA LandCover CCI (2015)

Product accuracy:

Landsat reference snow maps (open land):

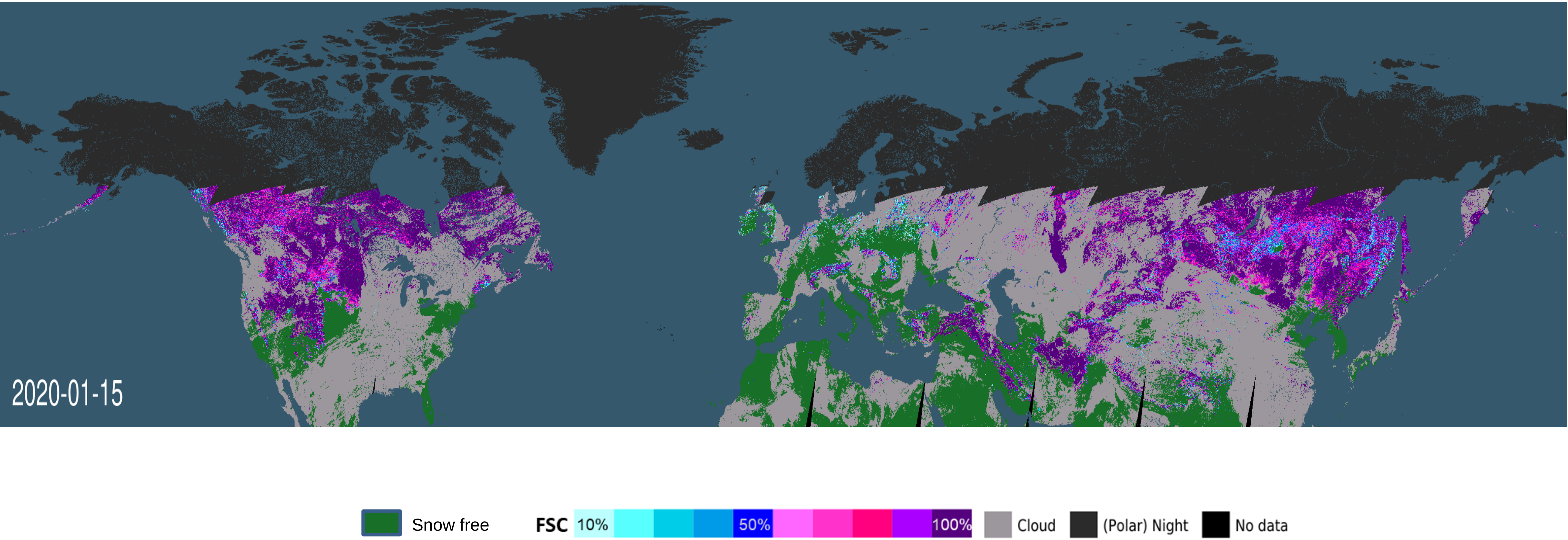
unbiased RMSE ~12%, Bias ~ -2 – -5%

Results from in-situ validation:

Metrics	FSC THR: 15% SD THR: 2cm	FSC THR: 10% SD THR: 1cm
Precision	0.8265	0.8793
Recall	0.9252	0.9012
F-Score	0.8731	0.8901
Omission error	0.0748	0.0988
Commission error, FAR	0.0913	0.0670
Overall Accuracy	0.9140	0.9218

Products generated from Sentinel-3 SLSTR from 2020 onwards

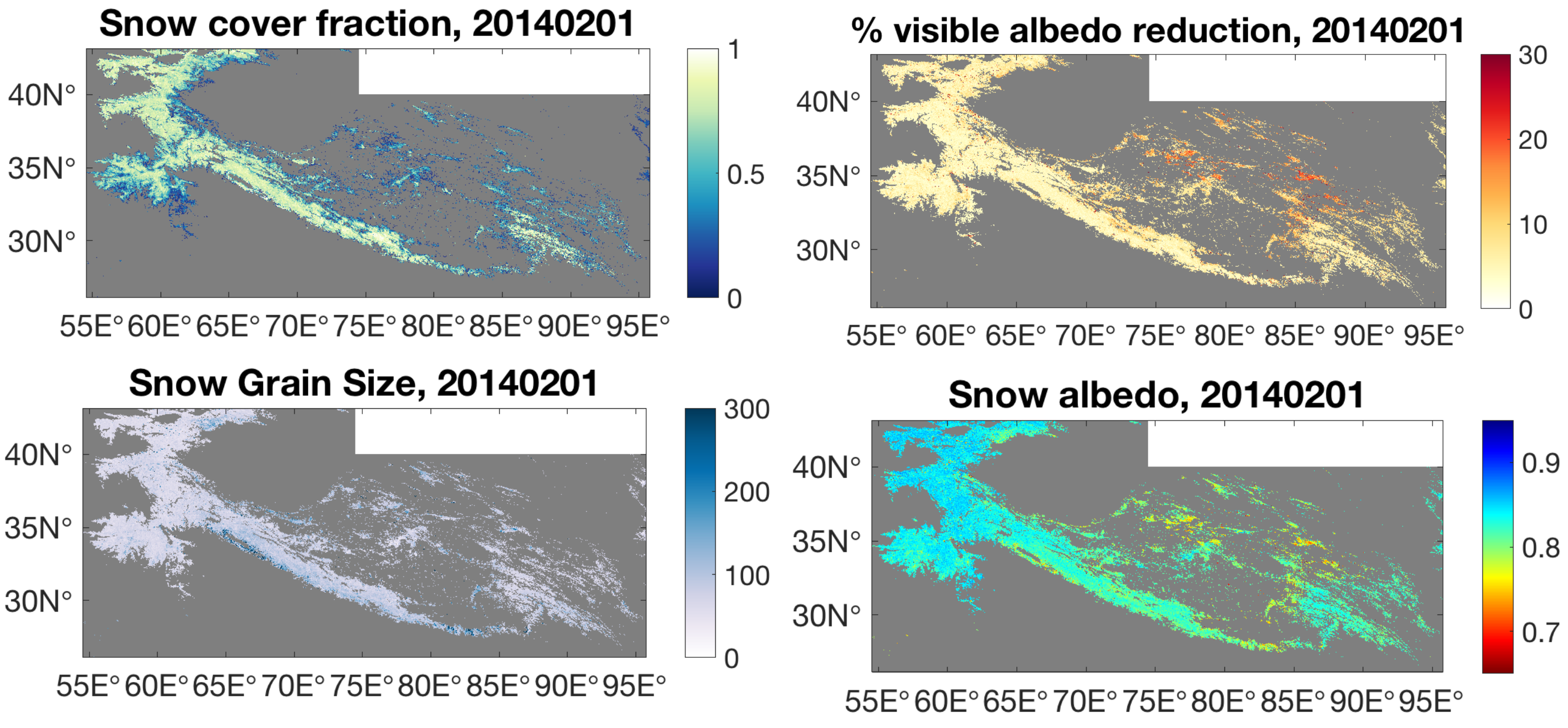
Sentinel-3 SLSTR based FSCG



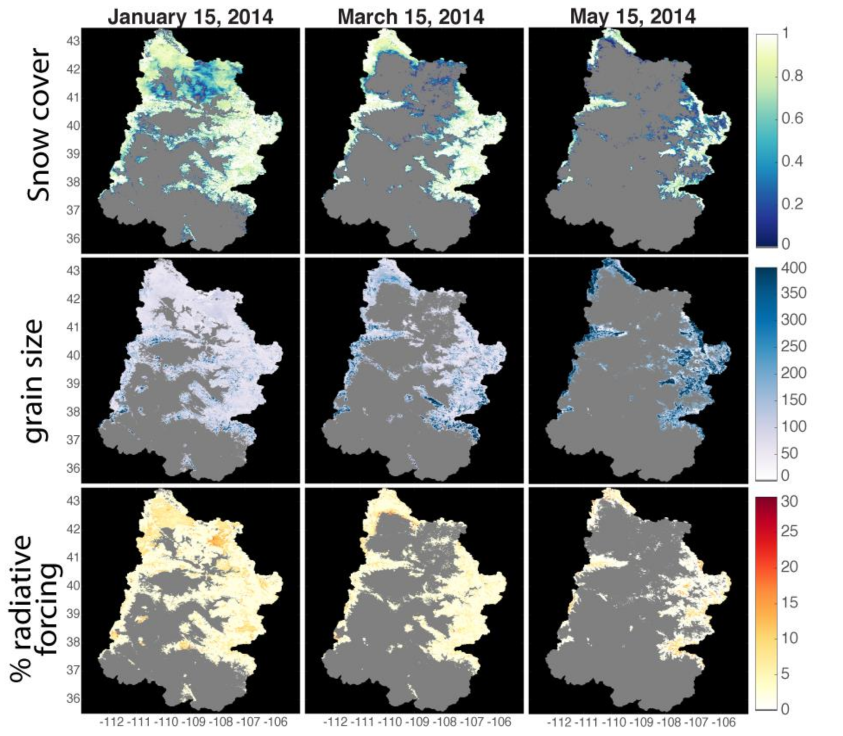
Product Summary Information CGLOPS NHEMI SCE

Product name	CGLOPS NHEMI SCE, Northern Hemisphere Snow Cover Extent of Copernicus Global Land Monitoring Service
Satellite & Sensor	Suomi-NPP VIIRS
Retrieval Algorithm	NDSI&BT based pre-classification of snow-free areas, SCAmod for FSC retrieval, SCDAv2.0 for cloud screening
Snow Parameter*	FSCG
Spatial Coverage	25°N – 84°N, 180W – 180E
Map Projection	Lat/lon, WGS84 (EPSG:4326)
Pixel spacing	0.01 x 0.01 degree
Temporal Coverage	09.01.2018 - present
Temporal Frequency	Daily
Accuracy Parameter **	None.
Accuracy Information ***	Accuracy from offline validation
Webpage	https://land.copernicus.eu/global/products/sce
Contact Point:	Gabriele Schwaizer, gabriele.schwaizer@enveo.at
References	Schwaizer, G., S. Metsämäki, and K. Luojus. 2019. Algorithm Theoretical Basis Document. Copernicus Global Land Operations – Lot 2, Snow Cover Extent – Collection 1km Northern Hemisphere, Version 1.0, Issue 1.02. CGLOPS2_ATBD_SCE-NHEMI-1km_V1, pp. 29. https://land.copernicus.eu/global/sites/cgls.vito.be/files/products/CGLOPS2_ATBD_SCE500-CEURO-500m-V1_I1.02.pdf

The Third Pole



Upper Colorado River basin



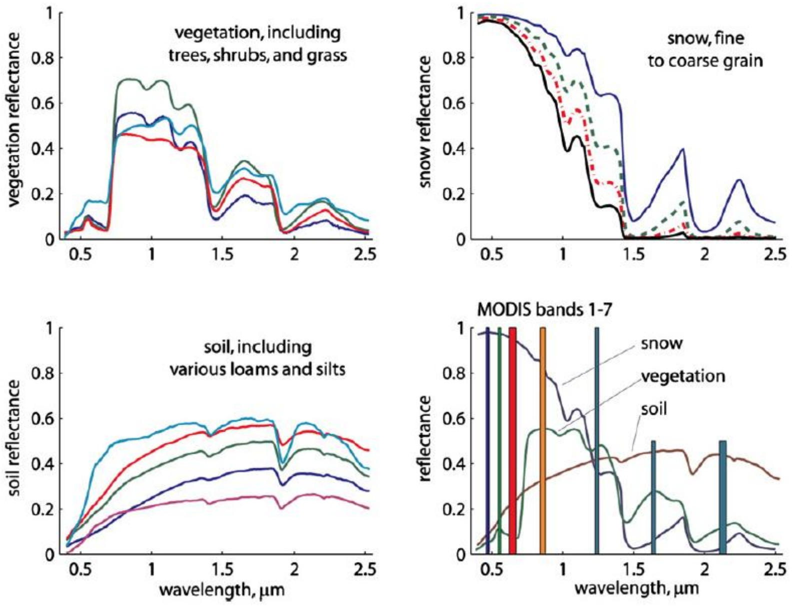
SCAG (snow cover and grain size)

and DRFS (dust radiative forcing)

Karl Rittger, University of Colorado, Boulder
Thomas Painter, University of California, Los Angeles
Jeff Dozier, University of California, Santa Barbara

Product algorithm and accuracy

Multiple endmember, linear spectral mixture analysis
Painter et al, RSE, 2009

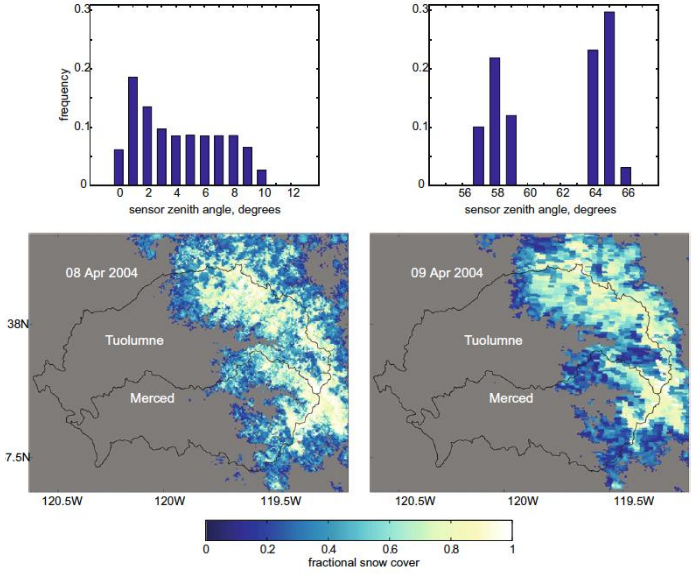


$$R_{S,\lambda} = \sum_{i=1}^{N} F_i R_{\lambda,i} + \varepsilon_\lambda$$

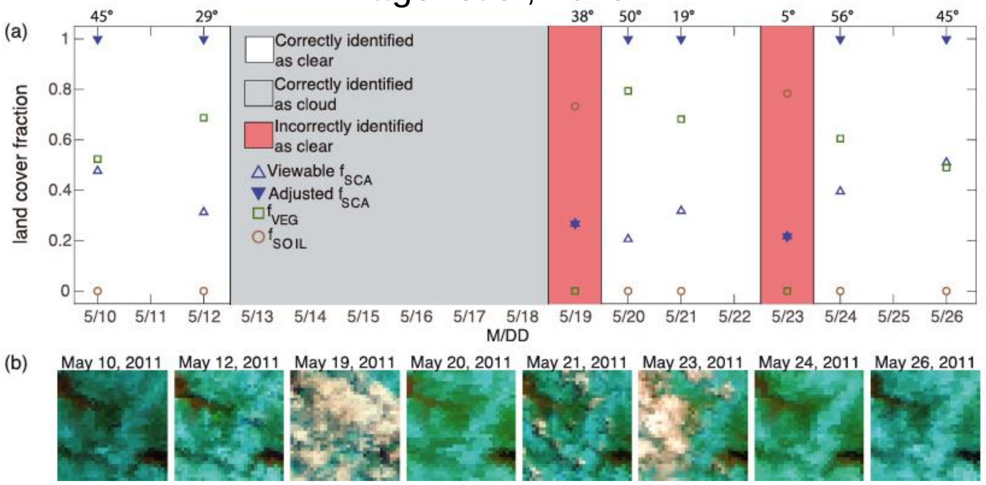
$$f_{SCA} = \frac{F_S}{\sum_{p\in s,v,r} F_p} = \frac{F_S}{1-F_{shade}}$$

$$RMSE = \left(\frac{1}{M}\sum_{\lambda=1}^{M}\varepsilon_\lambda^2\right)^{1/2}$$

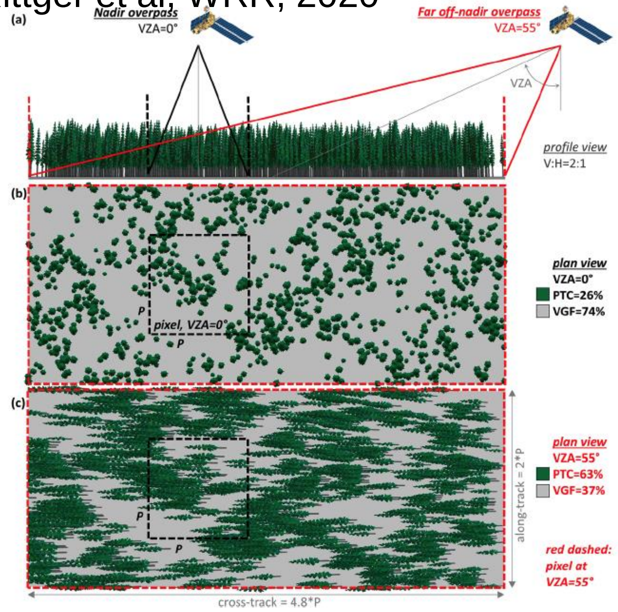
Off-nadir weighting
Dozier et al, WRR, 2008

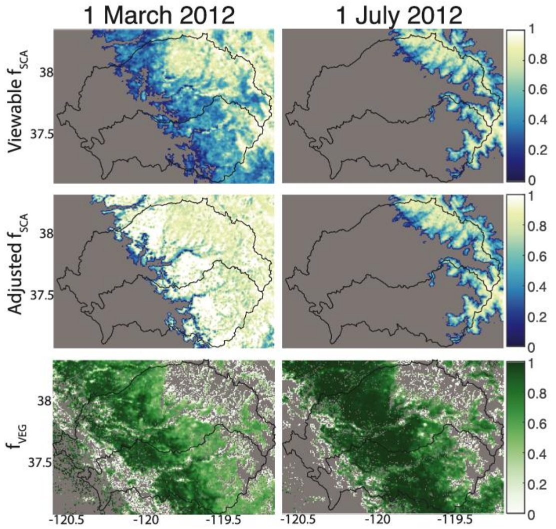


Cloud screening with non-snow endmembers
Rittger et al, 2019



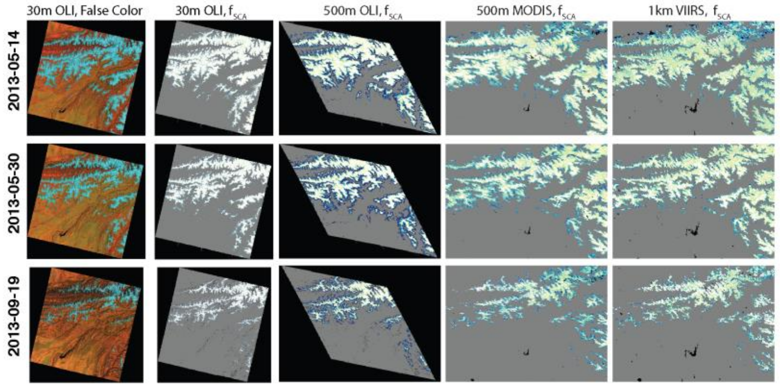
Adjustment from viewable (FSCV) to on the ground (FSCG)
Rittger et al, WRR, 2020



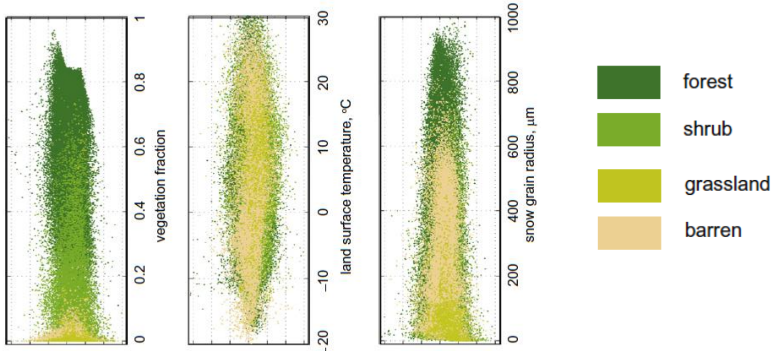


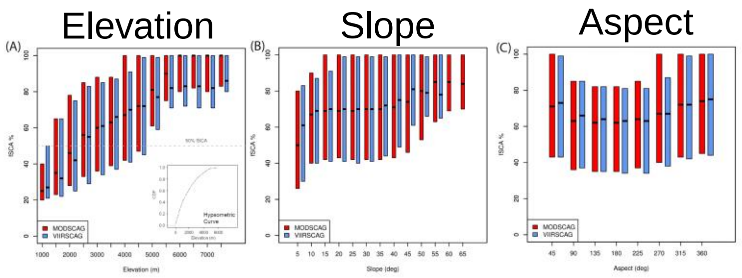
Product highlights

SCAG model performs similarly across multispectral instruments, scales, and landcover types

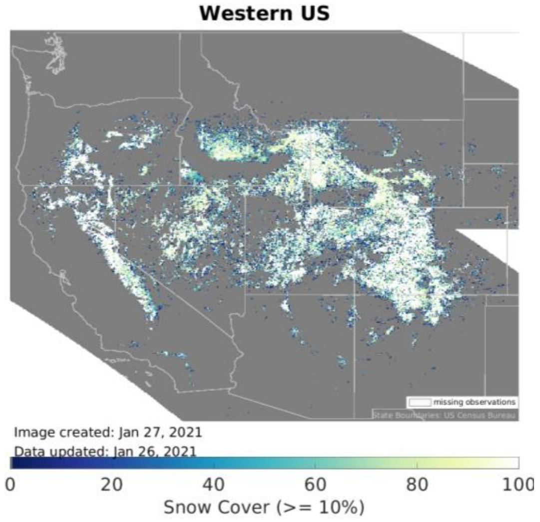


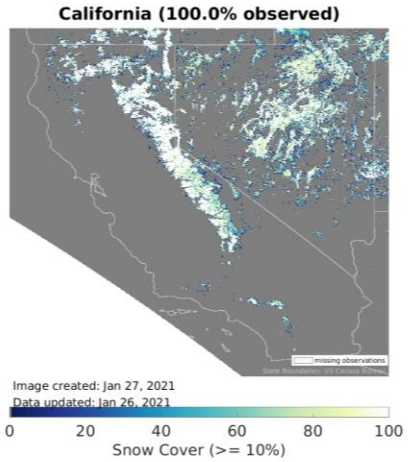
Statistic	MODIS	VIIRS
Recall	0.900	0.889
Precision	0.871	0.855
Fstat	0.883	0.867
Mean difference	-0.004	-0.013
Median difference	-0.002	-0.005
RMSE	0.133	0.125

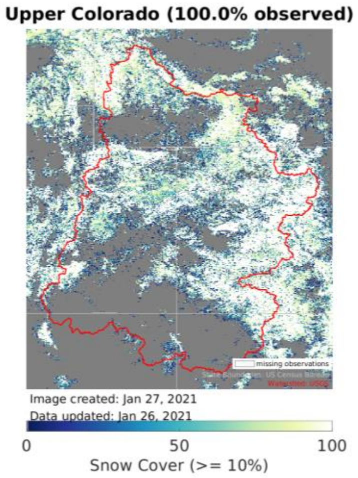




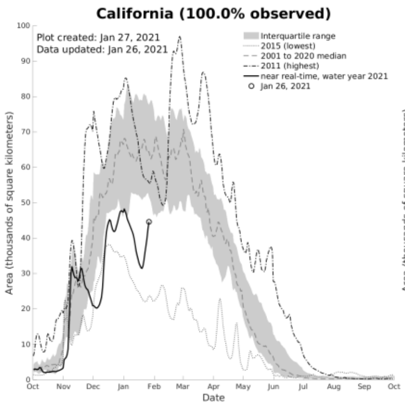
Available in NRT at NSDIC's Snow Today (Western US)
https://nsidc.org/reports/snow-today DOWNLOAD DATA

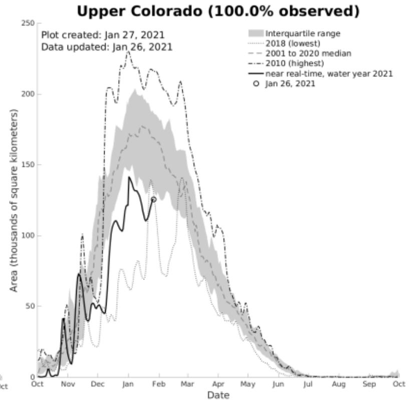




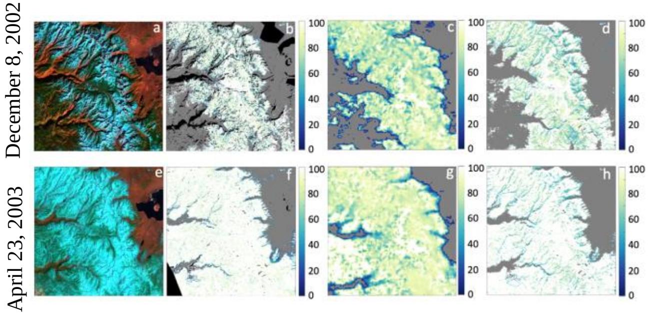


In context summaries comparing to satellite record



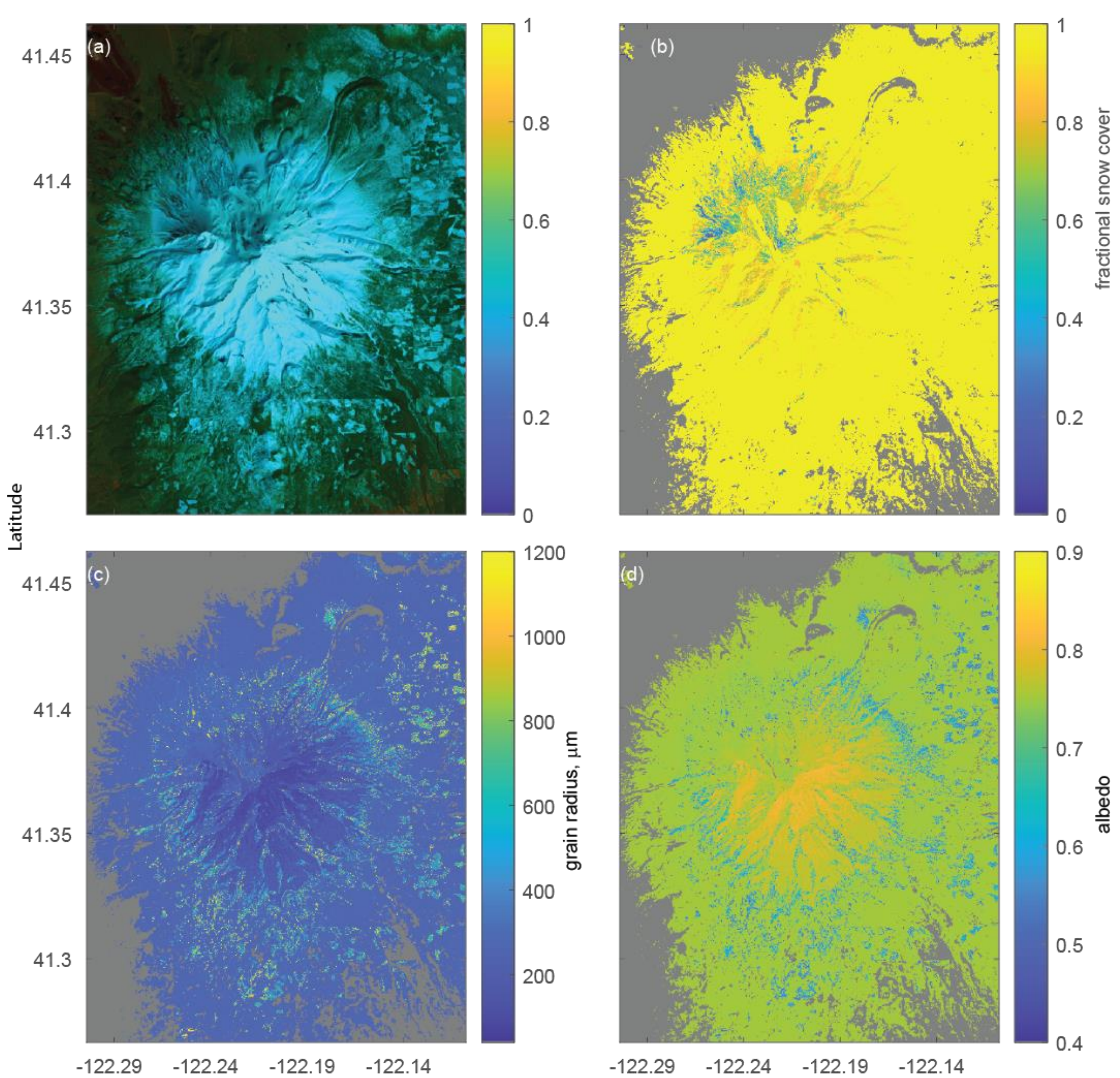


Landsat-MODIS fusion



Product Summary Information MODSCAG, MODDRFS

Product name	MODSCAG, MODIS Snow Covered and Grain size (also: TMSCAG, OLISCAG, VIIRSCAG) MODDRFS, MODIS Dust Radiative Forcing in Snow (also: TMDRFS, OLIDRFS, VIIRSDRFS)
Satellite & Sensor	Terra, MODIS
Retrieval Algorithm	Multiple endmember spectral mixture analysis
Snow Parameter*	FSC (both FSCV and FSCG)
Spatial Coverage	Western United States; Canadian Rockies and Alaska; High Mountain Asia; North Pole; South America
Map Projection	Sinusoidal
Pixel spacing	463 m
Temporal Coverage	For Version 6 MOD09GA 2000-2020 for 29 MODIS tiles; additional 40 tiles since April 2017
Temporal Frequency	Daily
Accuracy Parameter **	RMSE, Mean Diff, Median Diff, Precision, Recall, F-score
Accuracy Information ***	RMSE by pixel (internal estimate) for FSCV, above statistics summaries by season for FSCG
Webpage	Snow Today at NSIDC (https://nsidc.org/reports/snow-today). [JPL data access is not searchable]
Contact Point:	Karl Rittger, UCB Karl.Rittger@colorado.edu; Christine Lee, JPL Lee, christine.m.lee@jpl.nasa.gov>
References	Painter et al, RSE, 2009; Painter et al, GRL, 2012; Rittger et al, AdWR, 2013, Rittger et al, WRR, 2020; Rittger et al, Frontiers, submitted



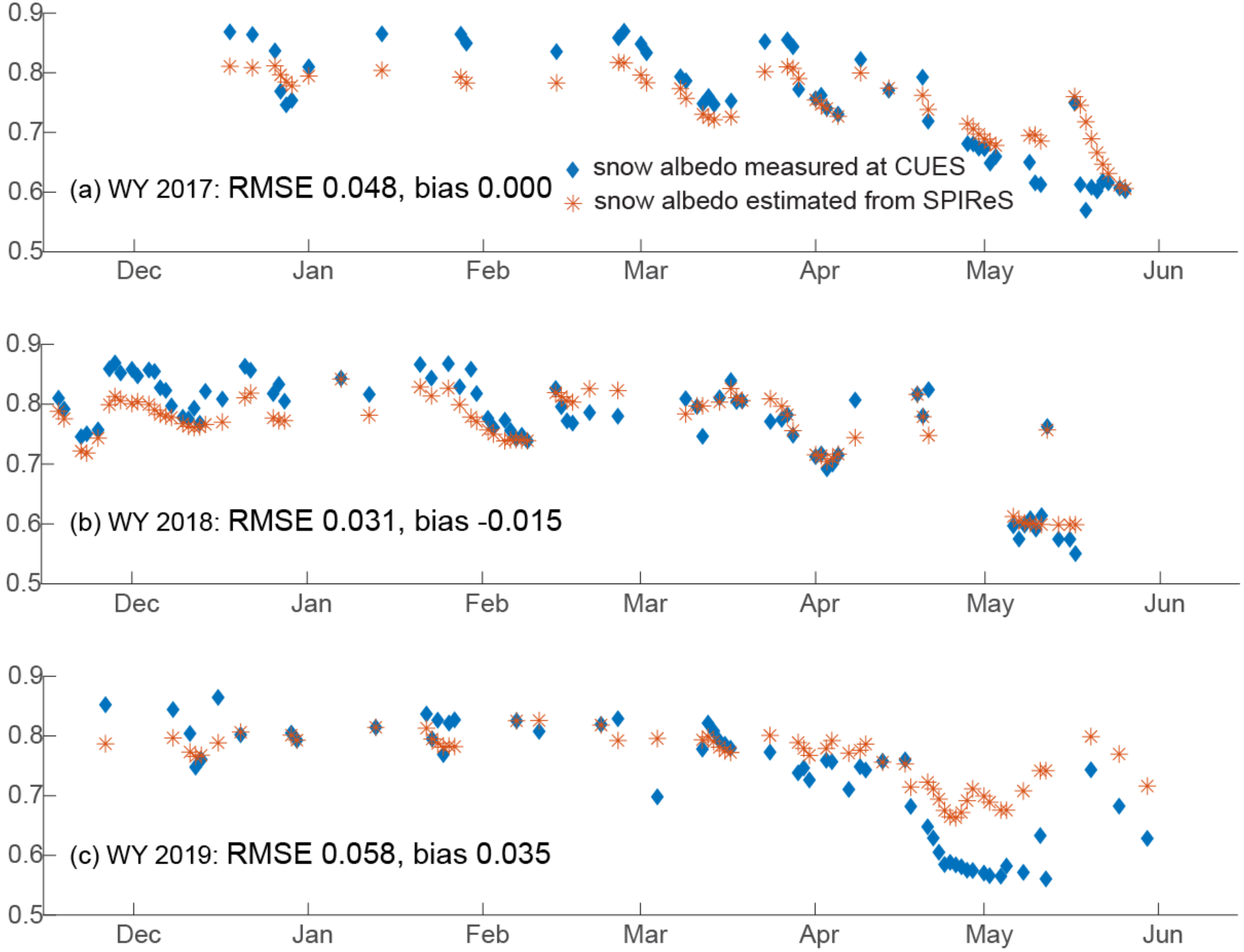
SPIReS

Edward Bair,
Timbo Stillinger,
Jeff Dozier, UCSB

Snow Property Inversion from Remote Sensing (SPIReS)

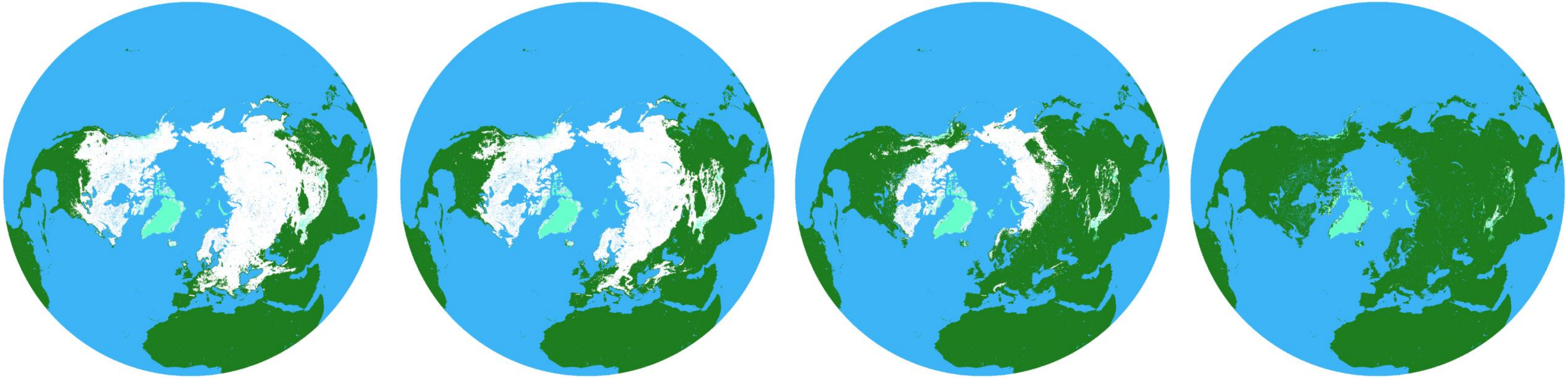
- Model pixel reflectance $R_{band}^{(model)} = \mathrm{f}\left(f_{SCA}, f_{shade}, r_g, \delta, \theta, v_f\ , R_0\right)$
  - r_g= effective grain radius, δ = dust/soot concentration, θ = illumination angle, v_f = topographic view factor, R_0 = spectrum of pixel when snow-free
  - (account for diffuse illumination, significant in blue and green)
  - (lookup tables for efficient calculation)
- Minimize $\left\| R^{(model)} - R^{(meas)} \right\|_2$ over all bands, constraints $\sum f = 1$ and $0 \leq \text{all}\ f \leq 1$
- Cloud screening based on spectrum, but smooth and interpolate over time so clouds also screened based on persistence
- Validated with Worldview 2/3 and Airborne Snow Observatory
- Solves for f_{SCA}, r_g, δ simultaneously, not sequentially

Albedo validation: MODIS vs CUES (CRREL/UCSB, Mammoth Mtn), 2017-2019



Product Summary Information SPIReS

Product name	SPIReS, Snow Property Inversion from Remote Sensing
Satellite & Sensor	Any multispectral sensor covering VSWIR, tested w MODIS & Landsat 8 OLI, Sentinel-2a/b next. Also configured for spectrometer, bands weighted by atmospheric transmittance.
Retrieval Algorithm	Minimize Euclidean norm: model (f_{SCA},r_g,dust) minus measurement (same as least squares).
Snow Parameter*	FSCG, grain size, dust/soot concentration, broadband albedo.
Spatial Coverage	Sierra Nevada California, 2001 through 2019 on the IEEE DataPort, **https://doi.org/10.21227/w6xt-8y49**
Source code	**https://github.com/edwardbair/SPIRES/releases/tag/v1.0**
Map Projection	MODIS sinusoidal.
Pixel spacing	463 m.
Temporal Coverage	2001 through 2019.
Temporal Frequency	Daily, smoothed and interpolated over time.
Accuracy Parameter	Bias, RMSE, Precision, Recall, F statistic (2×Precision×Recall)/(Precision+Recall)
Accuracy Information	71 MODIS scenes, medians for f_{SCA} Bias 0.004, RMSE 0.095, F 0.979
Contact Point:	E .H. Bair nbair@eri.ucsb.edu, T. Stillinger tcs@ucsb.edu, J. Dozier dozier@ucsb.edu.
References	***IEEE Trans Geosci. Remote Sens.* 2020**, **https://doi.org/10.1109/TGRS.2020.3040328**

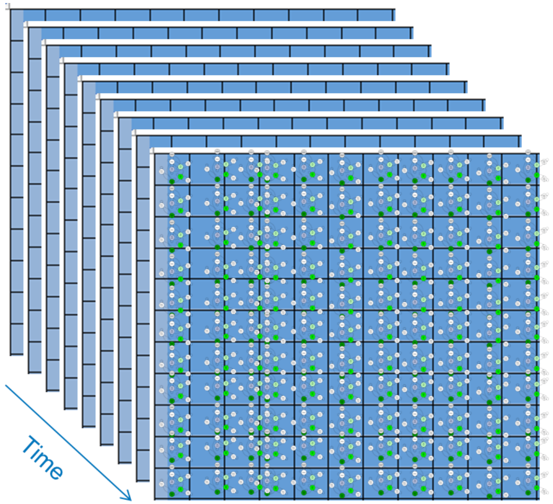


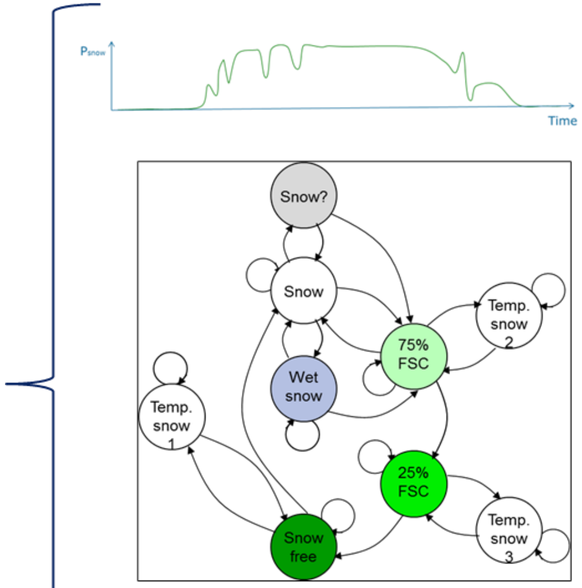
CryoClim

Rune Solberg, NR & Mari Anne Killie, MET Norway

Product algorithm and accuracy

- Implemented using a hidden Markov model (HMM) framework
- In HMM we observe a system assumed to evolve through a series of descrete states
- Transitions from one state to another happen with certain probabilities





$$p(X^t|E^t = S_i)$$

States: $Q = \{S_1, S_2, \dots, S_v\}$

Observables: $\bar{X}^T = \{X^1, X^2, \dots, X^T\}$

Prob. distr.: $p(X^t|E^t = S_i), i = 1, 2, \dots, v$

Transition probabilities.:

$$p\left(E^t = S_i \middle| E^{t-1} = S_j\right), i, j = 1, 2, \dots, v$$

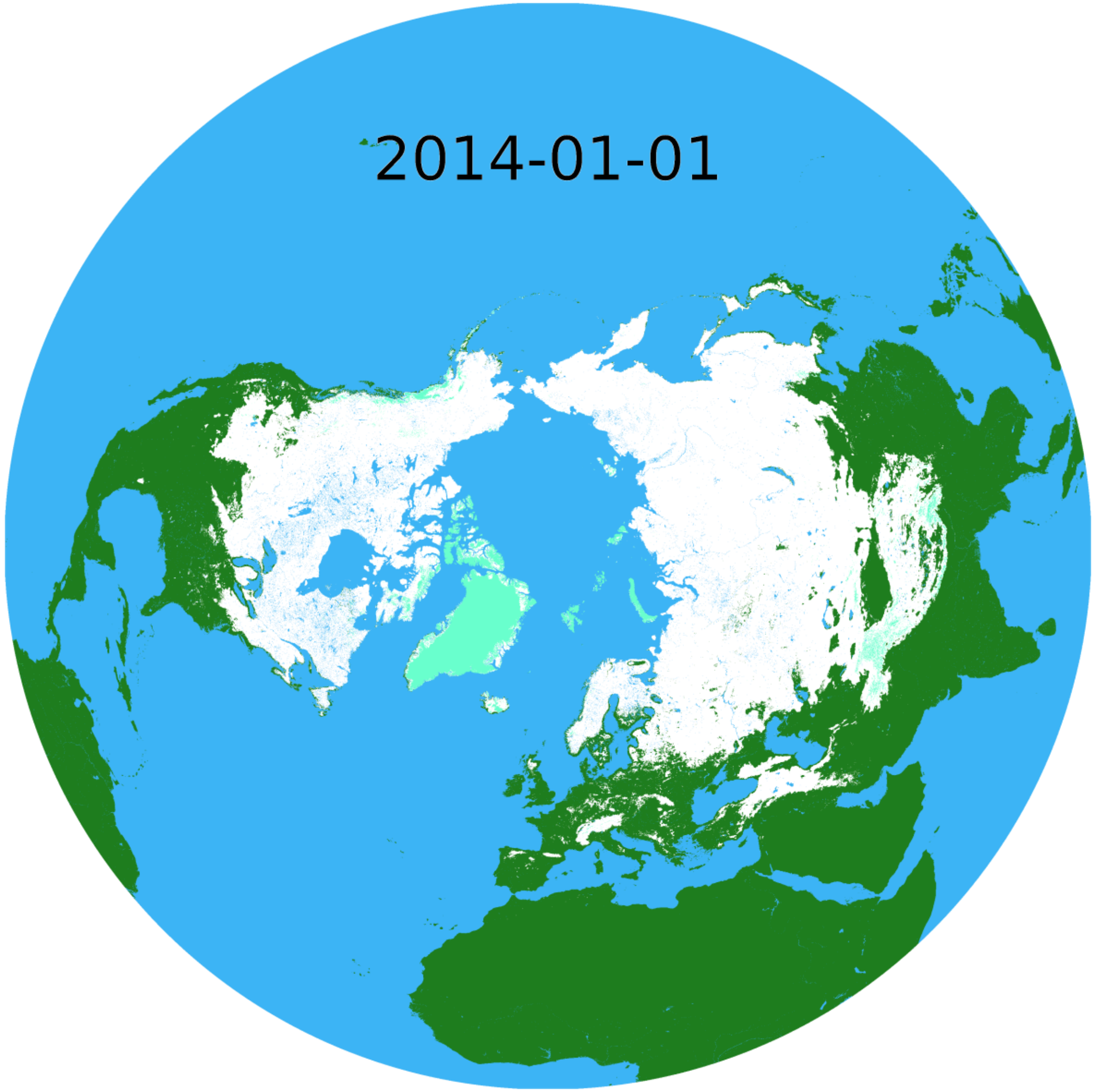
Initial conditions: $p(E^1 = S_i), i = 1, 2, \dots, v$

Viterbi algorithm: $V_{1,k} = p(X^1|k)p(E^1 = S_k)$

$$V_{t,k} = p(X^t|k) \max_i\left(p\left(E^t = S_i \middle| E^{t-1} = S_j\right)V_{t-1,k}\right)$$

- Validated using global network of meteorological stations
- Typical overall annual accuracy using GHCN-D is 93%
- Seasonal variations within 85-100% accuracy

Product highlights



Product highlights

15 January 2004

15 March 2004

15 May 2004

15 July 2004

Note the full spatial coverage without clouds and even coverage in the north during the polar night in January

Product Summary Information CryoClim SCE

Product name	CryoClim SCE, CryoClim Snow Cover Extent Product
Satellite & Sensor	AVHRR GAC and SMMR+SSM/I
Retrieval Algorithm	CryoClim multi-sensor multi-temporal HMM fusion algorithm
Snow Parameter*	SCE (SCEG) - Snow cover extent binary canopy corrected – FSCG under development
Spatial Coverage	Global (NH + SH maps)
Map Projection	EASE-Grid 2.0
Pixel spacing	5 km
Temporal Coverage	1982-2015 – until 2020 in progress
Temporal Frequency	Daily
Accuracy Parameter **	RMSE (estimated)
Accuracy Information ***	Per pixel
Webpage	cryoclim.net
Contact Point:	Rune Solberg, rune.solberg@nr.no / cryoclim@nr.no
References	R. Solberg, M. A. Killie, L. M. Andreassen and M. König, CryoClim: A new system and service for climate monitoring of the cryosphere, IOP Conf. Series: Earth and Environmental Science 17 (2014) 012008

EUMETSAT H SAF products H10 / H31 (H32)

Matias Takala, Niilo Siljamo Finnish Meteorological Institute
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Niilo.siljamo@fmi.fi

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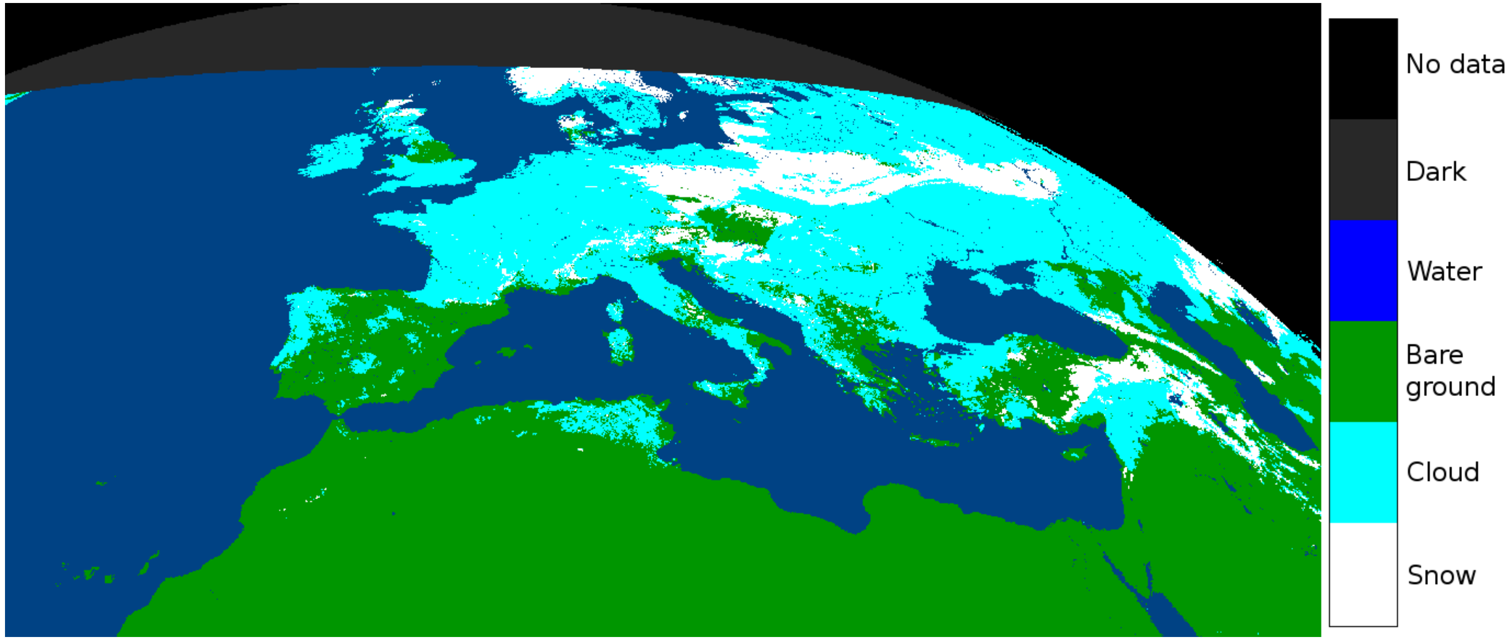
FINNISH METEOROLOGICAL INSTITUTE

Snow Extent H10

- Operational NRT daily product
- Download at hsaf.meteoam.it
- Product is actually a merge of two products:
  - FMI part for flat lands
  - TSMS (Turkish State Meteorological Service) part for mountains
- Both parts are based on MSG SEVIRI data
- FMI part is derived from product H31 developed originally for LSA SAF
- Covers Pan European area
- Product H34 is pre-operational and is otherwise the same as H10 but will cover whole SEVIRI disk
- For scientific details please refer to ATBD document available at download site



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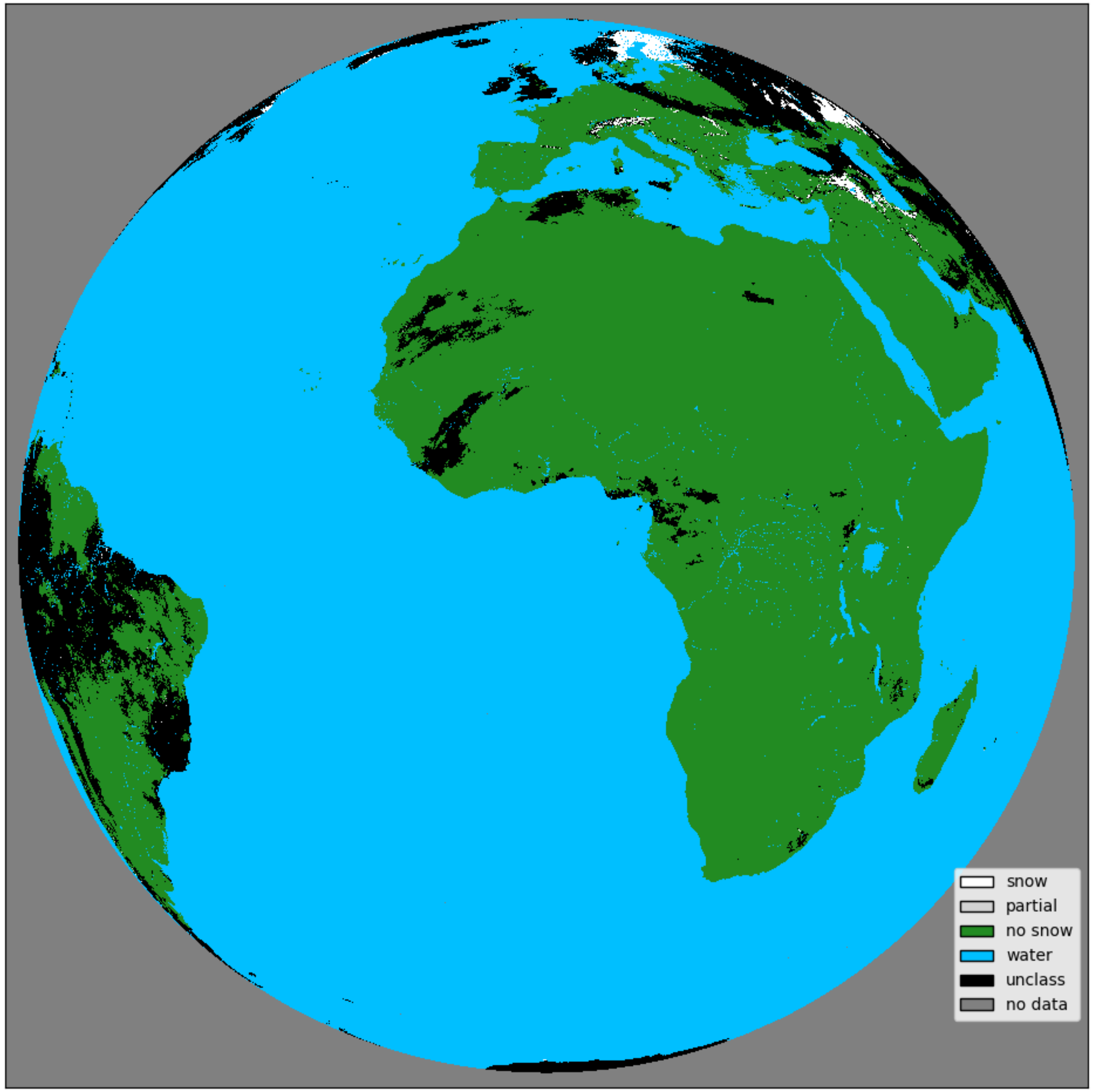
Snow extent H31

- Operational NRT daily product
- Download at landsaf.ipma.pt
- H31 was developed in LSA SAF context but is now in H SAF domain
- Product is produced by FMI only
- based on MSG SEVIRI data
- Covers whole SEVIRI disk
- H31 is the input for H10 product
- There are differences between H10 and H31, please refer PUM (Product User Manual) for details

- Siljamo, Niilo, and Otto Hyvärinen. "New Geostationary Satellite–Based Snow-Cover Algorithm", Journal of Applied Meteorology and Climatology 50, 6 (2011): 1275-1290, https://doi.org/10.1175/2010JAMC2568.1

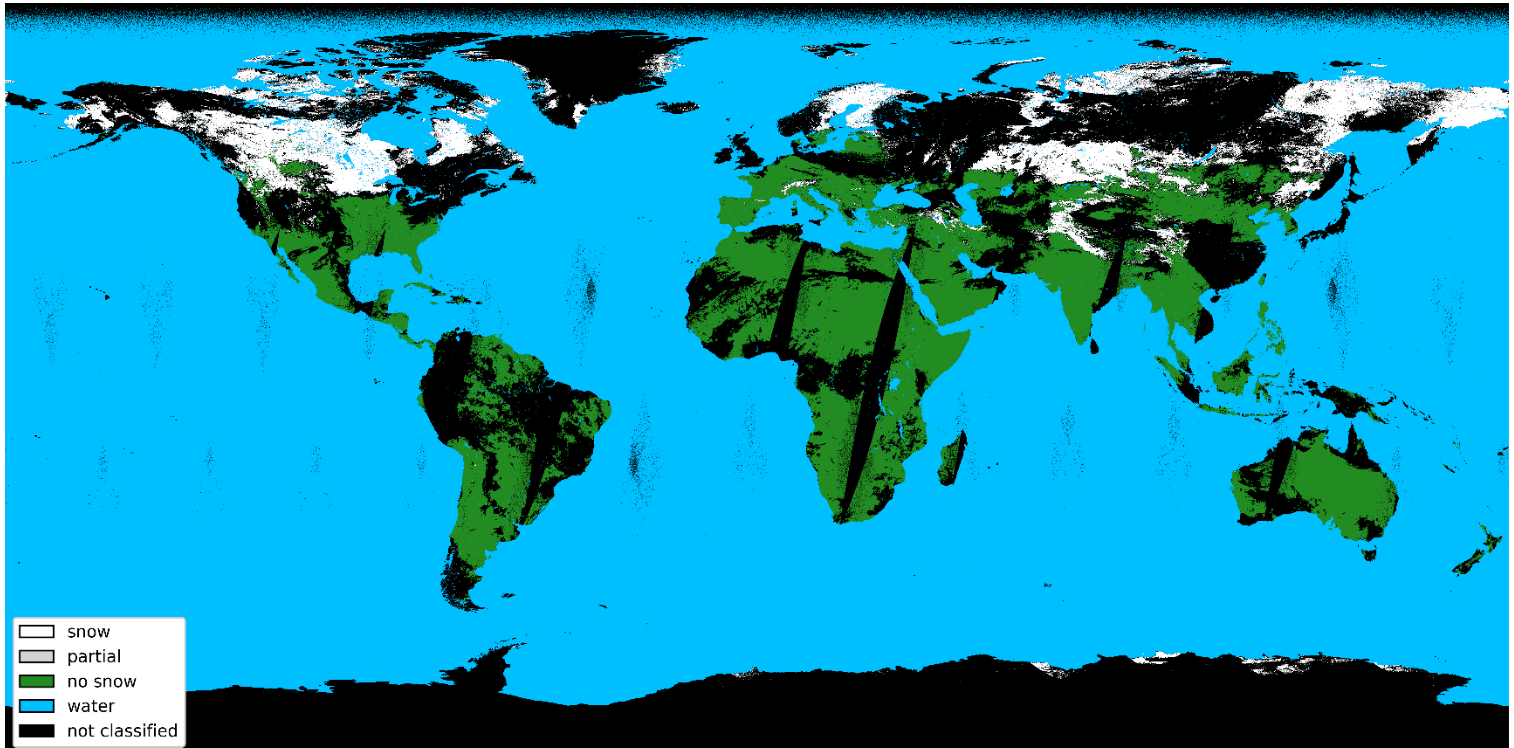
MSG/SEVIRI snow cover 22.3.2019



Snow Extent H32

- Operational NRT daily product
- Download at landsaf.ipma.pt
- H32 was developed in LSA SAF context but is now in H SAF domain
- Product is produced by FMI only
- H32 is based on Metop/AVHRR data
- Standalone product
- Siljamo, Niilo, Otto Hyvärinen, Aku Riihelä, and Markku Suomalainen. "MetOp/AVHRR Snow Detection Method for Meteorological Applications", Journal of Applied Meteorology and Climatology 59, 12 (2020): 2001-2019, https://doi.org/10.1175/JAMC-D-20-0032.1

Metop/AVHRR snow cover 22.3.2019



SNOW WATER EQUIVALENT PRODUCTS

snowpex+

esa

JAXA Daily Snow Depth Product
Satellite-based Microwave Snow Algorithm (SMSA)

Richard Kelly, University of Waterloo

Product algorithm and uncertainty estimation

Approach

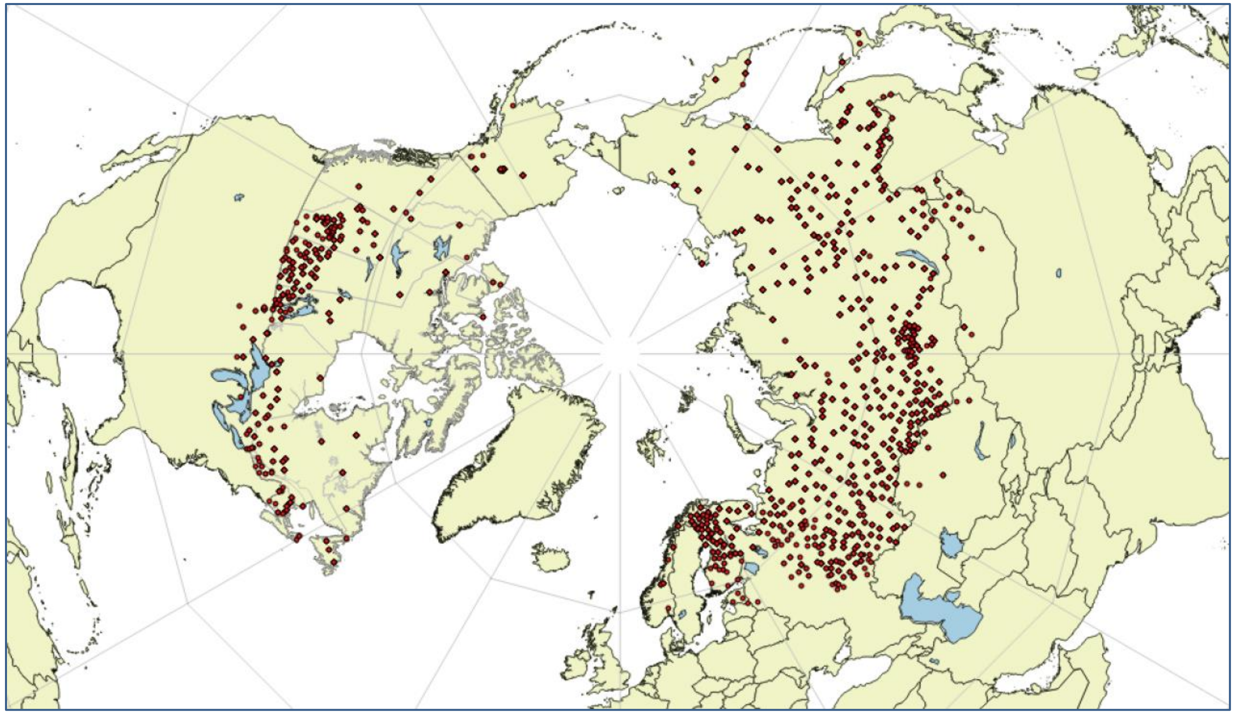
- Snow detection: AMSR2 Tb obs. coupled with Auxilliary data. Snow typing: shallow/moderate/wet.
- Snow depth retrieval: single layer DMRT model LUT. AMSR2 Tb parameterization of *d0*, ρ, T_{phys}. Cost function minimizes $(Tb18\text{-}Tb36)_{est}$ and $(Tb18\text{-}Tb36)_{obs}$. (H or V pol depending on snow detection)
- Temporal inertia: gaussian weighted Tb data incorporated.
- Bias correction from unresolved forest attenuation
- SWE estimated as a bi-product of DMRT and ρ
- Algorithm grid 12.5 EASE2 ➔ L2 Product granule (lat/lon) ➔ L3 PSG NH product

Auxilliary Data

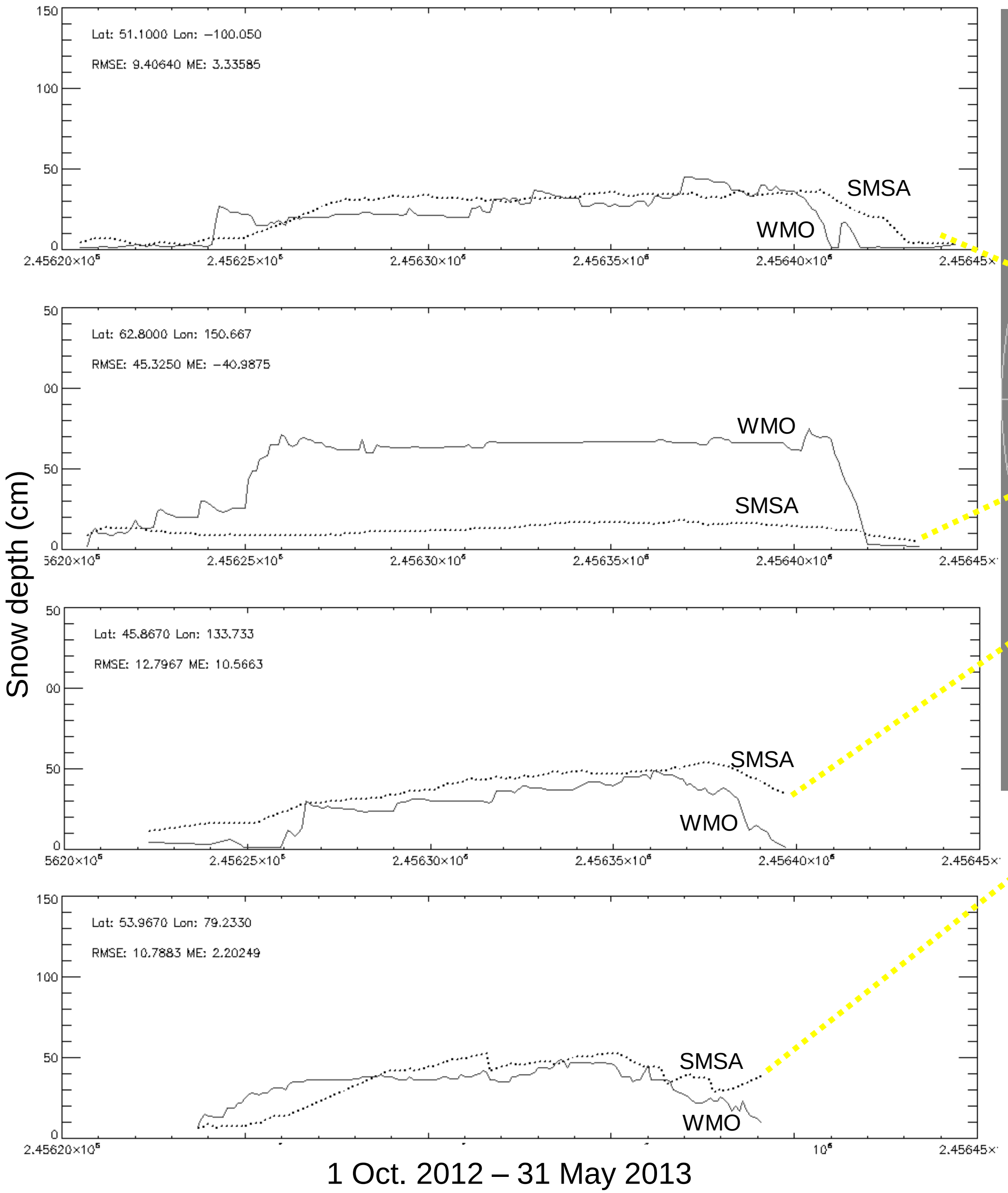
- Forest transmissivity (Li and Kelly, 2017)
- DEM (UNEP)
- Land Ocean Ice mask
- Water fraction
- SoilsGrid250m (Hengl *et al*. 2017)

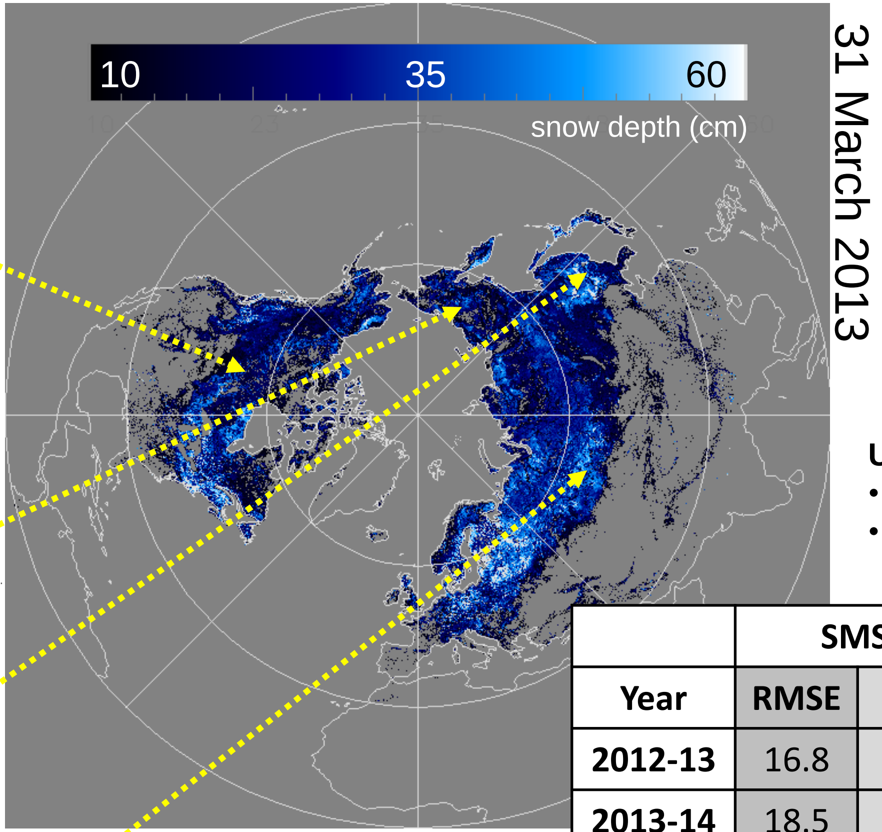
Uncertainty estimation

- WMO GSOD snow depth – *in situ* point locs.
- >100 snow days (SD>0) per season
- <100cm observed depth
- RMSE, MBE estimates



Product highlights. Uncertainty estimates (station-wise)





Uncertainty metrics

- SMSA is new version (used here)
- Current (v2) is in production at JAXA (was used in SnowPEx)

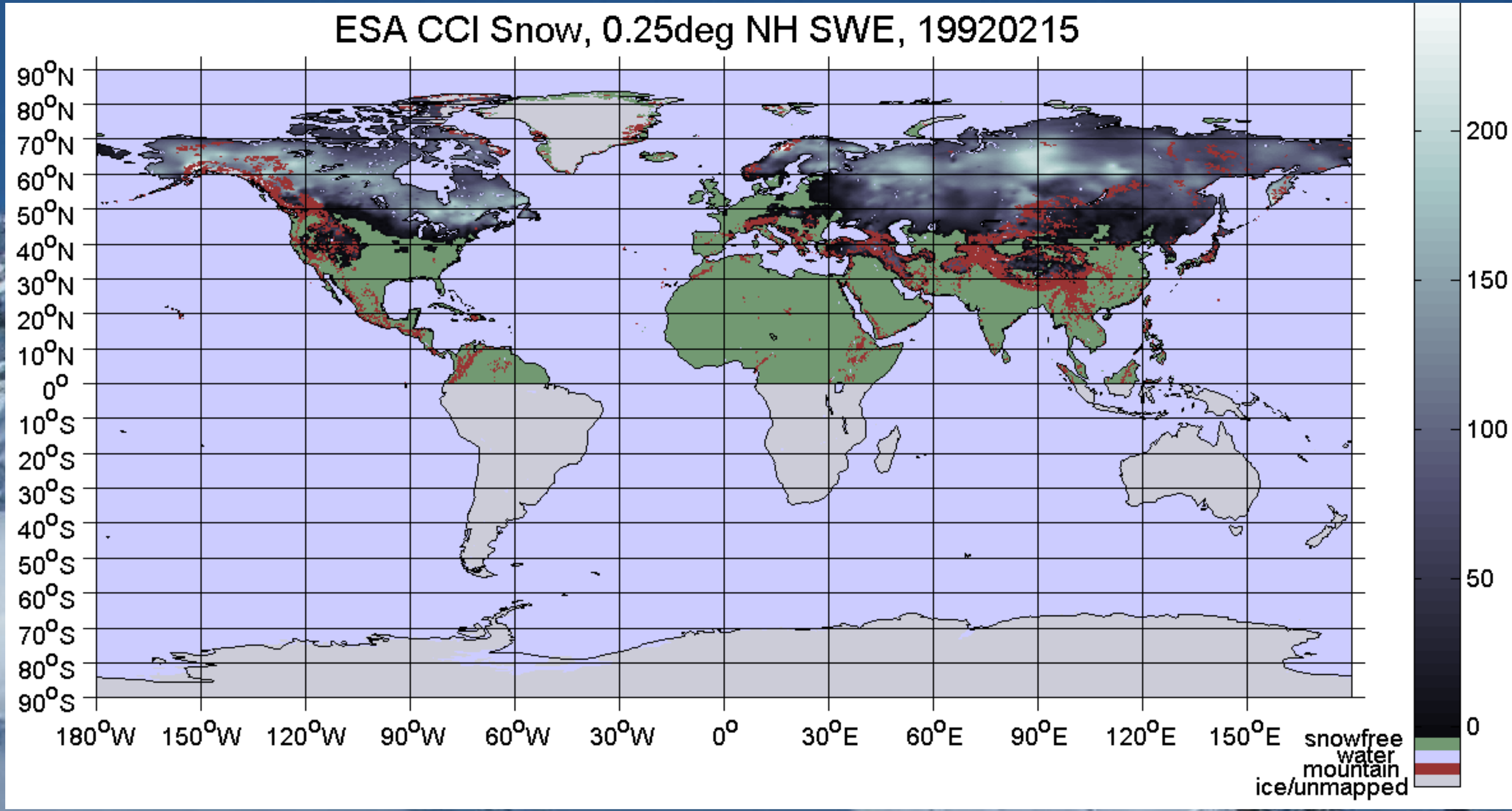
Site selection

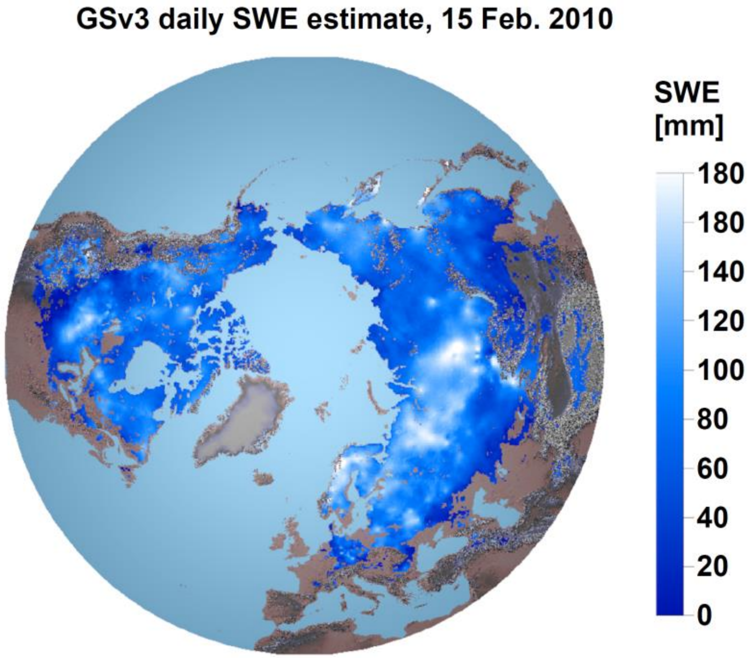
- Only stations that have >100 days with snow depth >0 each year used
- Average number of stations per year: 545 (range: 373-649)

	SMSA (new)			Current (v2)		
Year	**RMSE**	**MAE**	**ME**	**RMSE**	**MAE**	**ME**
2012-13	16.8	14.4	-0.4	20.4	16.8	-3.5
2013-14	18.5	15.9	-2.1	23.2	19.7	-5.0
2014-15	19.3	16.8	-1.0	23.9	20.1	-2.5
2015-16	18.1	15.6	0.0	22.8	19.3	-3.7
2016-17	19.0	16.3	-1.6	23.9	20.2	-8.0
2017-18	19.6	17.1	-1.2	24.8	21.0	-4.5
2018-19	18.2	15.8	-1.6	23.5	19.3	-4.2
Average	**18.5**	**16.0**	**-1.1**	**23.2**	**19.5**	**-4.5**

Product Summary Information JAXA Snow Depth

Product name	JAXA Daily Snow Depth Product
Satellite & Sensor	GCOM-W AMSR2
Retrieval Algorithm	Satellite-based Microwave Snow Algorithm – DMRT-ML LUT and cost function (δTb minimization)
Snow Parameter*	Snow Depth & SWE
Spatial Coverage	Northern and Southern Hemisphere
Map Projection	EASE2 Grid *in algorithm*
Pixel spacing	12.5 km
Temporal Coverage	2012-present
Temporal Frequency	Daily
Accuracy Parameter **	RMSE / MBE snow depth
Accuracy Information ***	WMO GSOD snow depth data 2012-2019. Station-wise per season. Can be expanded.
Webpage	https://suzaku.eorc.jaxa.jp/GCOM_W/index.html (NB existing product is not SMSA but previous version that was evaluated in SnowPEx)
Contact Point:	Richard Kelly, rejkelly@uwaterloo.ca
References	Kelly, R.E.J., Chang, A.T.C, Tsang, L. and Foster, J.L. (2003) Development of a prototype AMSR-E global snow area and snow volume algorithm, IEEE TGARS, 41(2): 230-242.





Bias-corrected SWE estimates

ESA Snow CCI SWE

Kari Luojus, FMI

J. Pulliainen, M. Takala, J. Lemmetyinen, M. Moisander, P. Venäläinen, et al. (FMI)
C. Derksen, et al. (ECCC)

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snowpex

snow cci

Product algorithm and accuracy

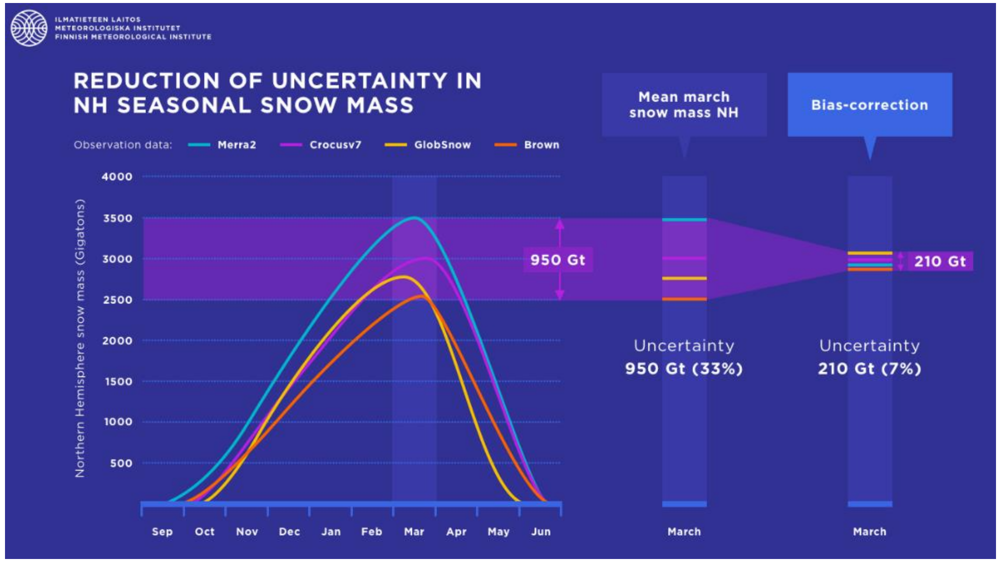
- Input data: Nimbus-7 SMMR, DMSP F-series SSM/I and SSMIS, combined with synoptic weather station snow depth observations
- Auxiliary data: ESA BIOMASAR (stem volumes), ESA CCI land cover (water mask), ETOPO5 (mountain mask)
- Algorithm: Updated GlobSnow retrieval algorithm (Pulliainen 2006 / Takala et. al 2011 / Luojus et al. 2021)
- Accuracy estimation: Overall RMSE of 52.6 mm; 32.7 mm (for SWE below 150 mm)
- Limitations: mountains, glaciers and ice sheets not retrieved;
  deep snow (>150mm is a known challenge)

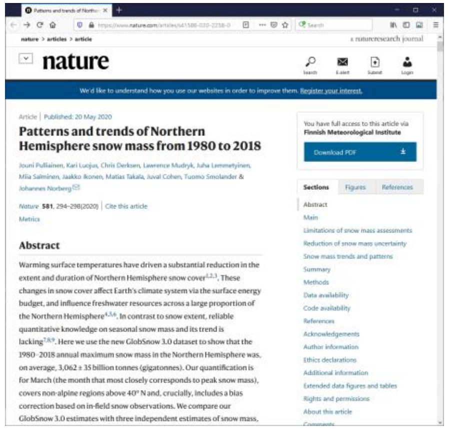
- Method assessed with other SWE datasets in SnowPEx-1 and reported in Mortimer et al. 2020 Cryosphere article

Mortimer, C., Mudryk, L., Derksen, C., Luojus, K., Brown, R., Kelly, R. and Tedesco, M., "Evaluation of long-term Northern Hemisphere snow water equivalent products", The Cryosphere, vol 14, no. 5, pp. 1579-1594. https://doi.org/10.5194/tc-14-1579-2020, 2020.

Snow CCI SWE highlights – Long term CDR + bias-correction

A Significant spread in NH snow mass between the Satellite and model-based estimates.
-> A new bias-correction methodology (Nature, May 2020) decreases this uncertainty significantly! -> Allowing us to determine for the first time reliably the trends and patterns of the NH snow mass for 1980-2018!

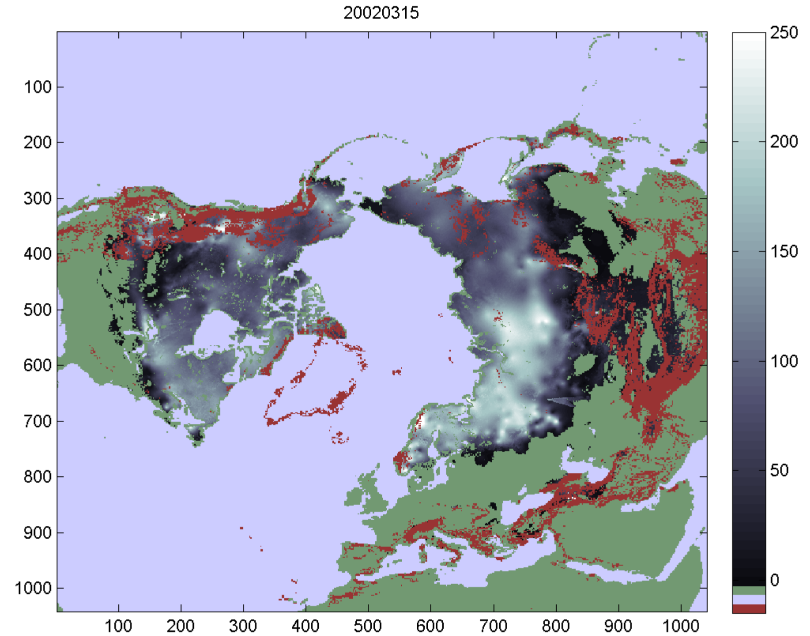




Pulliainen, J., Luojus, K., Derksen, C. et al. Patterns and trends of Northern Hemisphere snow mass from 1980 to 2018.
Nature 581, 294–298 (2020).
https://doi.org/10.1038/s41586-020-2258-0

Further SWE retrieval R&D

- Improved spatial resolution EASE2 12.5km / 0.10º lat/lon
- Improved retrieval methodology
- Homogenized & augmented input datasets
- Ensemble of SWE products
- Synergistic optical / PMW SWE product



Product Summary Information

Product name	ESA Snow CCI SWE v1.0
Satellite & Sensor	Nimbus-7 SMMR, DMSP F-series SSM/I, SSMIS
Retrieval Algorithm	Updated GlobSnow retrieval alg. (Pulliainen 2006 / Takala et. al 2011)
Snow Parameter*	Snow Water Equivalent (SWE)
Spatial Coverage	Northern Hemisphere (excluding mountains, glaciers, ice sheets)
Map Projection	Lat/lon projection
Pixel spacing	0.25º lat/lon (Snow CCI SWE v2.0 -> 0.10º lat/lon grid to be available in late 2021)
Temporal Coverage	January 1979 – June 2019
Temporal Frequency	Daily (monthly)
Accuracy Parameter **	Per-pixel uncertainty: Statistical standard deviation of SWE estimate (includes consideration statistical + systematic error components on a pixel level)
Accuracy Information ***	Overall RMSE of 52.6 mm; 32.7 mm for SWE below 150 mm.
Webpage	Snow CCI data portal (+ PANGAEA & https://www.globsnow.info/swe/archive_v3.0/)
Contact Point:	Kari Luojus, kari.Luojus@fmi.fi
References	Luojus, K., et al., “GlobSnow v3.0 Northern Hemisphere Snow Water Equivalent Dataset,” Scientific Data, (in press) 2021.

Gridded Reanalysis-Driven SWE Products

- Gridded SWE datasets from reanalysis (in various forms) increase the product sample size
- As in SnowPEx-1, these datasets will be assessed alongside products which include EO
- Focus will be on non-mountain regions
- Patricia will provide an overview the ERA5 family of products

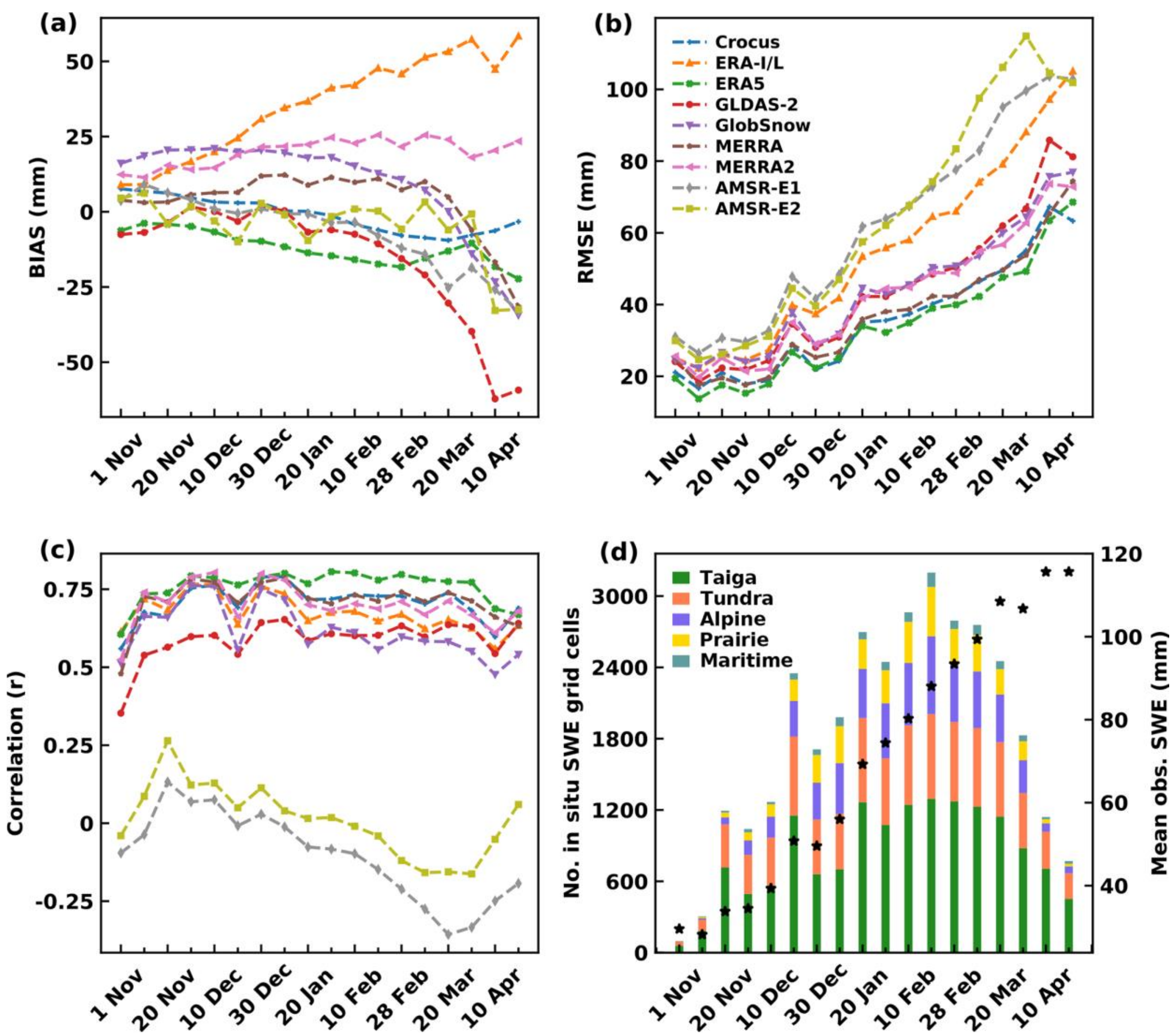
Products

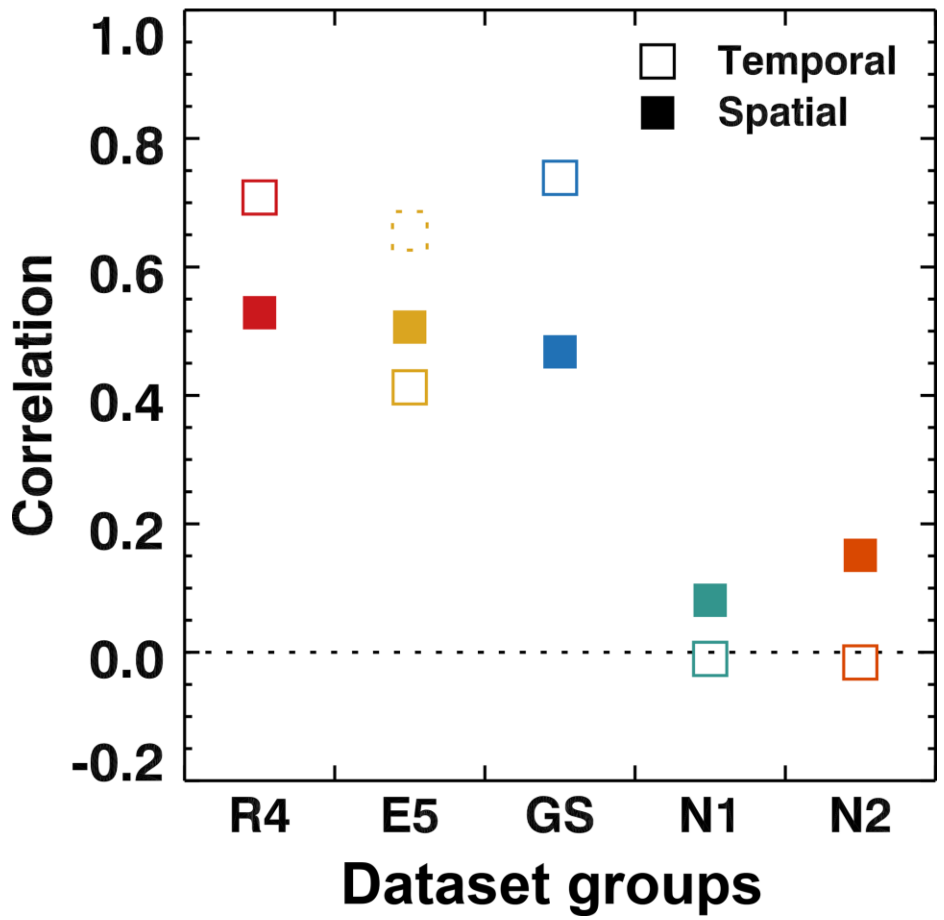
Family	Sub-Family	Product	Time Period	Resolution/ Grid	Description	Point of Contact/ References
Reanalysis (land-atmosphere coupled)	Atmospheric-modern	MERRA2	1980-present	0.5 deg lat/lon	-no directly assimilated land surface observations -time integration of surface meteorological conditions by the GEOS-5 Catchment land model (3 snow layers) -latitude dependent observation-corrected precipitation	rolf.h.reichle@nasa.gov Gelaro et al., 2017 Reichle et al., 2017
	Atmospheric-historical	20CRv3	1836-2015	0.5 deg lat/lon	-NCEP Global Spectral Model atmosphere coupled to Noah land surface model (single snow layer)	clara.draper@noaa.gov Slivinski et al., 2019
	Surface snow depth assimilation	ERA5	1950-2020	31 km	-2D-OI using SYNOP snow depth observations -IMS assimilation for snow extent starting in 2004 -HTESSEL land surface scheme (single snow layer)	hans.hersbach@ecmwf.int Hersbach et al., 2019
		ERA5-snow	1980-present	31 km	-uncoupled land surface DA -HTESSEL land surface scheme -ready ~Jan. 2021	patricia.rosnay@ecmwf.int de Rosnay 2020 pers. comm.
		JRA55	1958-present	55 km	-2D-OI using SYNOP snow depth observations -JMA Simple Biosphere (SiB) model (single snow layer) -passive microwave derived snow extent starting in 1987	yuki-kosaka@met.kishou.go.jp Kobayashi et al., 2015 Onogi et al., 2007

Products

Family	Sub-Family	Product	Time Period	Resolution/ Grid	Description	Point of Contact/ References
Reanalysis + Snow Model	Temp-index model	Brown_ERA5	1981-present	31 km	-simple snow accumulation, aging and melt model driven by ERA5 air temperature and precipitation	lawrence.mudryk@canada.ca Brown et al., 2003
	Simple snow model	GEMv2-SVSv1	2000-2018 1980-2018	10 km	-SVS simulations (single snow layer) -GEM-regional forcing (initialized by ERAint) with post-production precipitation analysis -under development, ready before Apr. 2021 -ready after Apr. 2021	vincent.vionnet@canada.ca Vionnet 2020 pers. comm.
	Complex snow model	Crocus_ERAintv7	1981-2017	0.5 deg lat/lon	-Crocus snow model forced by ERAint	bertrand.decharme@meteo.fr Brun et al., 2013
		Crocus_ERAintv8	1981-2018	0.5 deg lat/lon	-Crocus snow model forced by ERAint; temporal update to v7	bertrand.decharme@meteo.fr Brun et al., 2013
		Crocus_ERAintv9	1981-2019	0.5 deg lat/lon	-Crocus snow model forced by ERAint; temporal update to v8 -unusually low Arctic snow in 2019?	bertrand.decharme@meteo.fr Brun et al., 2013
		Crocus_ERA5	1950-present		-Crocus snow model forced by ERA5 -under development at M-F	bertrand.decharme@meteo.fr
		ERA5-land	1950-present	0.1 deg lat/lon	-replay of the land component of the ERA5; HTESSEL land surface scheme -no synop or IMS assimilation	joaquin.munoz@ecmwf.int Munoz-Sabater et al., in prep
	GRACE assimilation	GLDASv2.2	2003-present	0.25 deg lat/lon	-Catchment-F2.5 in Land Information System (LIS) Version 7 (3 snow layers) forced by ECMWF IFS -assimilation of GRACE-derived TWS anomalies (150,000 km resolution) added to the temporal mean of the model simulated TWS	bailing.li@nasa.gov matthew.rodell@nasa.gov hiroko.kato-1@nasa.gov Li et al., 2018

Product uncertainty

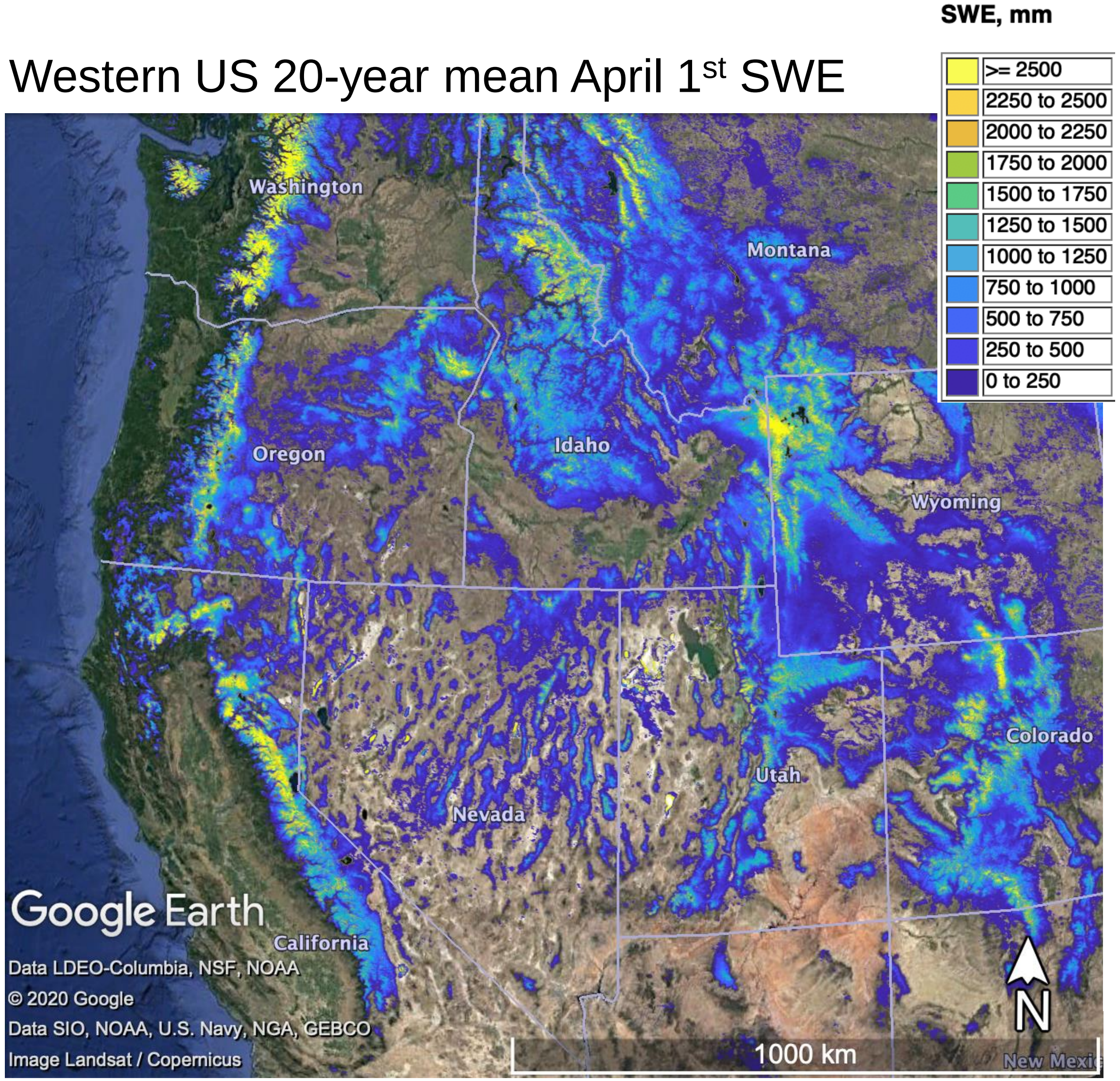


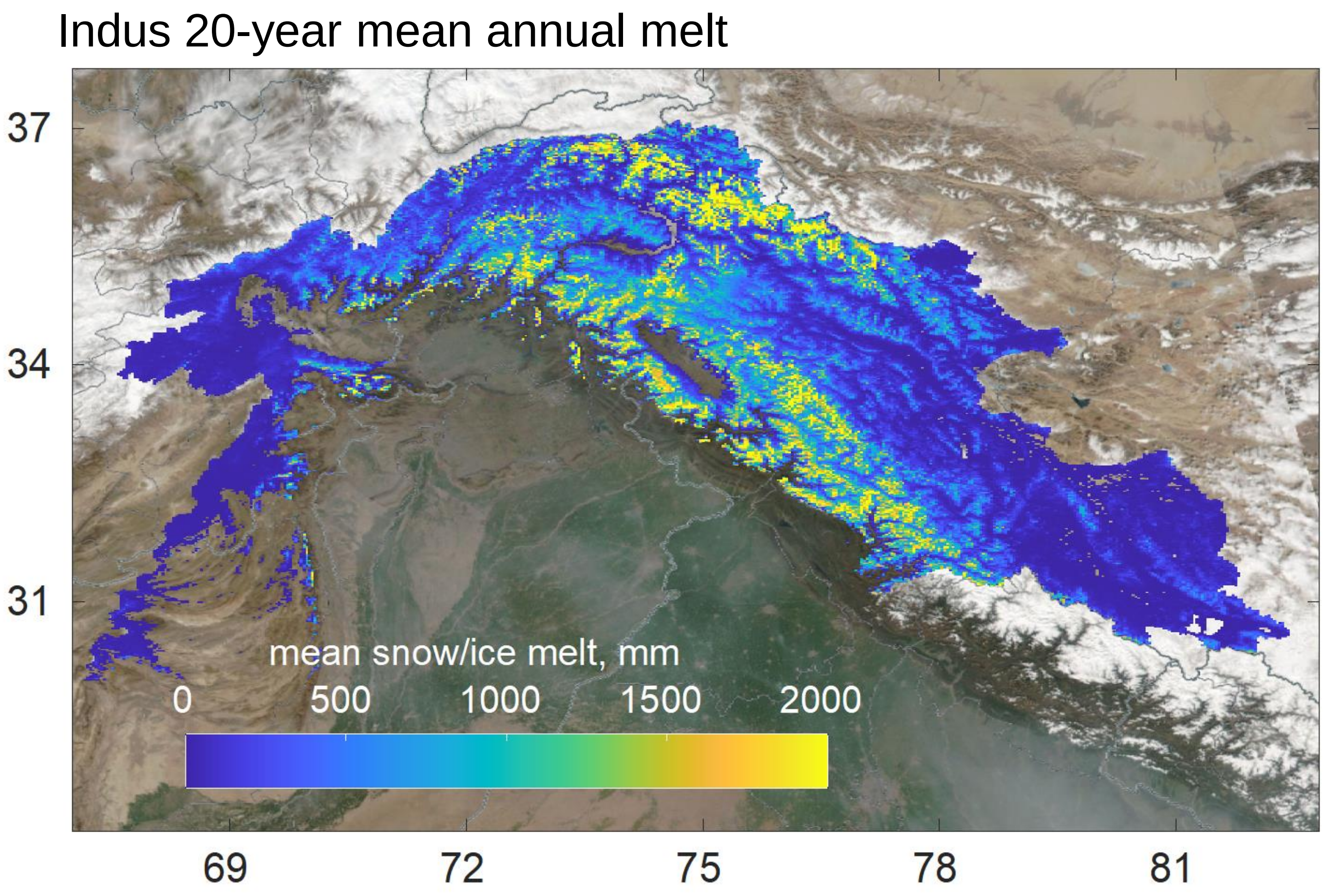


Mortimer et al., 2020

Product specifications Gridded-Reanalysis-SWE

Product name	Gridded Reanalysis-Driven SWE Products
Satellite & Sensor	
Method	Reanalysis driven
Parameter*	SWE
Spatial Coverage	Northern Hemisphere (non-mountain)
Map Projection	lat/lon
Pixel spacing	Variable
Pixel reference**	
Temporal Coverage	2015-2020 (validation) 1980-2020 (trends)
Temporal Frequency	Daily
Accuracy	Variable
Product coding range	Variable
References	See previous table
Webpage	





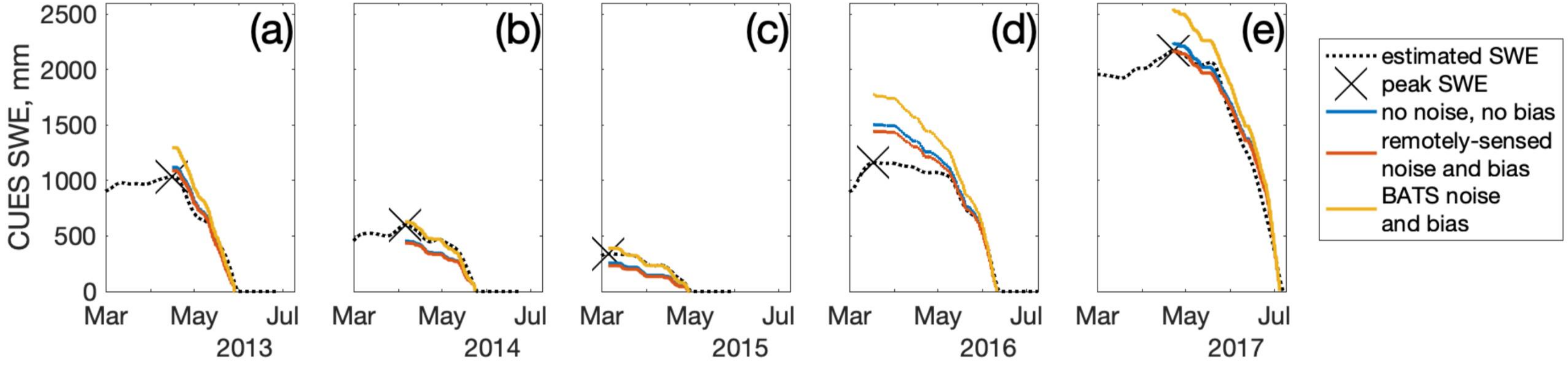
The Parallel Energy Balance Model

Edward (Ned) Bair, UCSB; Karl Rittger, CUB

Product algorithm and accuracy

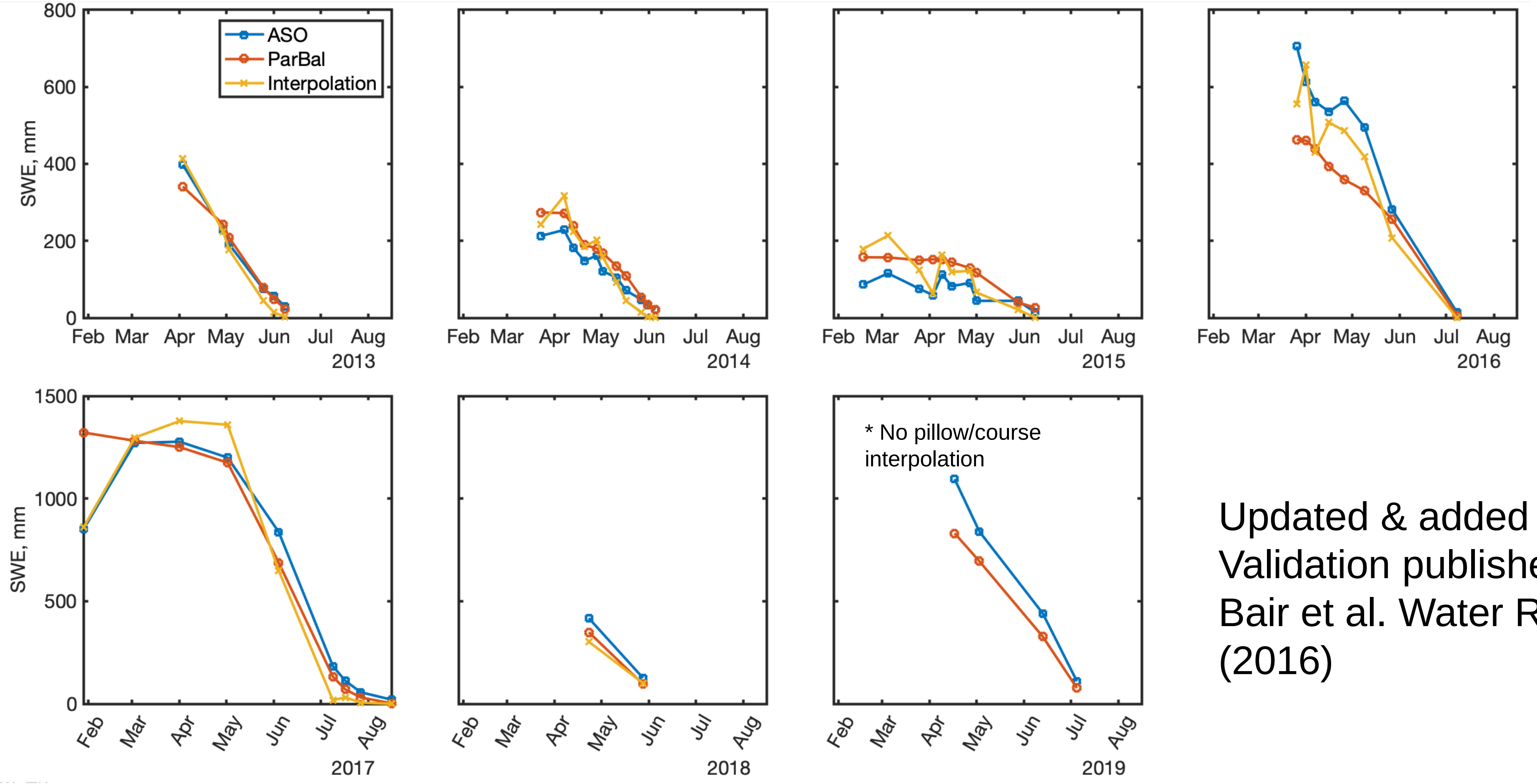
- Direct estimation of the water stored in the snowpack using satellites is difficult. We rely on a technique called snow water equivalent (SWE) reconstruction.
- Using optical satellite sensors with daily repeat mapping (e.g. MODIS or VIIRS), we can accurately predict the fraction snow covered area (fSCA), although we do not know its depth.
- Thus, we combine the estimates of snow covered area with downscaled energy balance calculations to estimate how much snow melted everyday of the year.
- Further, we can sum this melt up to estimate the SWE on the ground during, from melt out to the peak SWE.

Bair et al (2019), Water Res. Research



Validation

- Using Airborne Snow Observatory estimates of basin-wide SWE over the Upper Tuolumne, CA USA for 2013 - 2019: 26% MAE and 2% bias
- Versus pillow/course interpolation: 35% MAE and -21% bias



Updated & added 2016-2019 to Validation published in Bair et al. Water Res. Research (2016)

Product Summary Information ParBal

Product name	ParBal, Parallel Energy Balance Model
Satellite & Sensor	MODIS or VIIRS, MODIS Landsat 8 daily 30 m fusion work in progress
Retrieval Algorithm	MODSCAG/DRFS or SPIRES for SCE combined with downscaled energy balance modeling
Snow Parameter*	SWE or melt
Spatial Coverage	Run on demand; Complete Indus and Western US for MODIS-era (2001-2020)
Map Projection	sinusoidal
Pixel spacing	463 m
Temporal Coverage	2001-2020
Temporal Frequency	daily
Accuracy Parameter **	MAE and Bias
Accuracy Information ***	Basin-wide SWE validation
Webpage	https://snow.ucsb.edu; https://github.com/edwardbair/ParBal
Contact Point:	Edward (Ned) Bair, nbair@eri.ucsb.edu
References	Bair et al. WRR (2016); Rittger et al. ADWR (2016)

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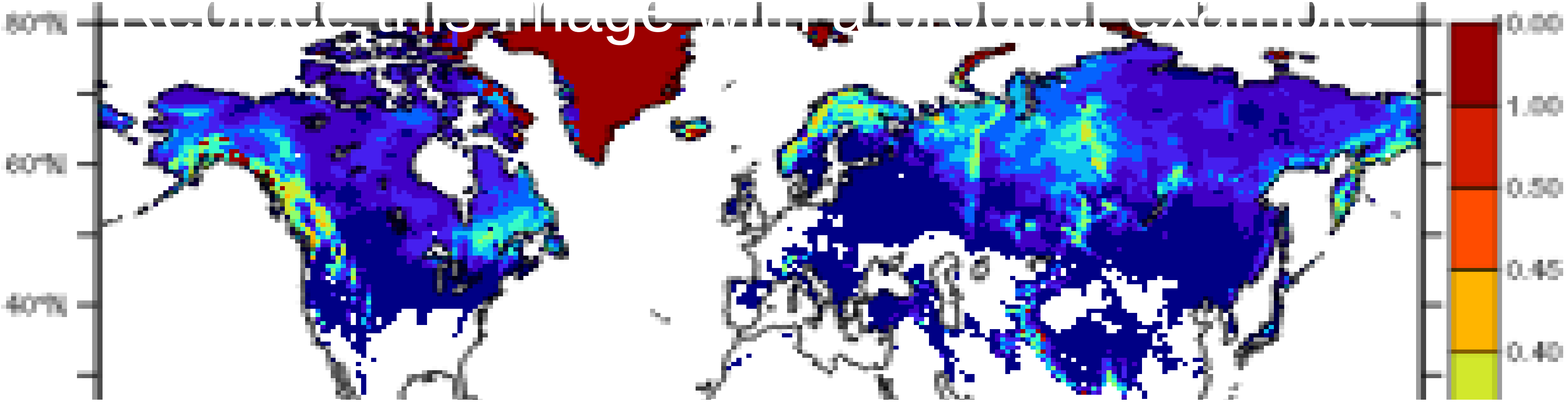


ERA5 family: ERA5, ERA5-Land, ERA5-Snow SWE reanalysis and model products

Patricia de Rosnay, Joaquin Munoz-Sabater, Hans Hersbach
ECMWF

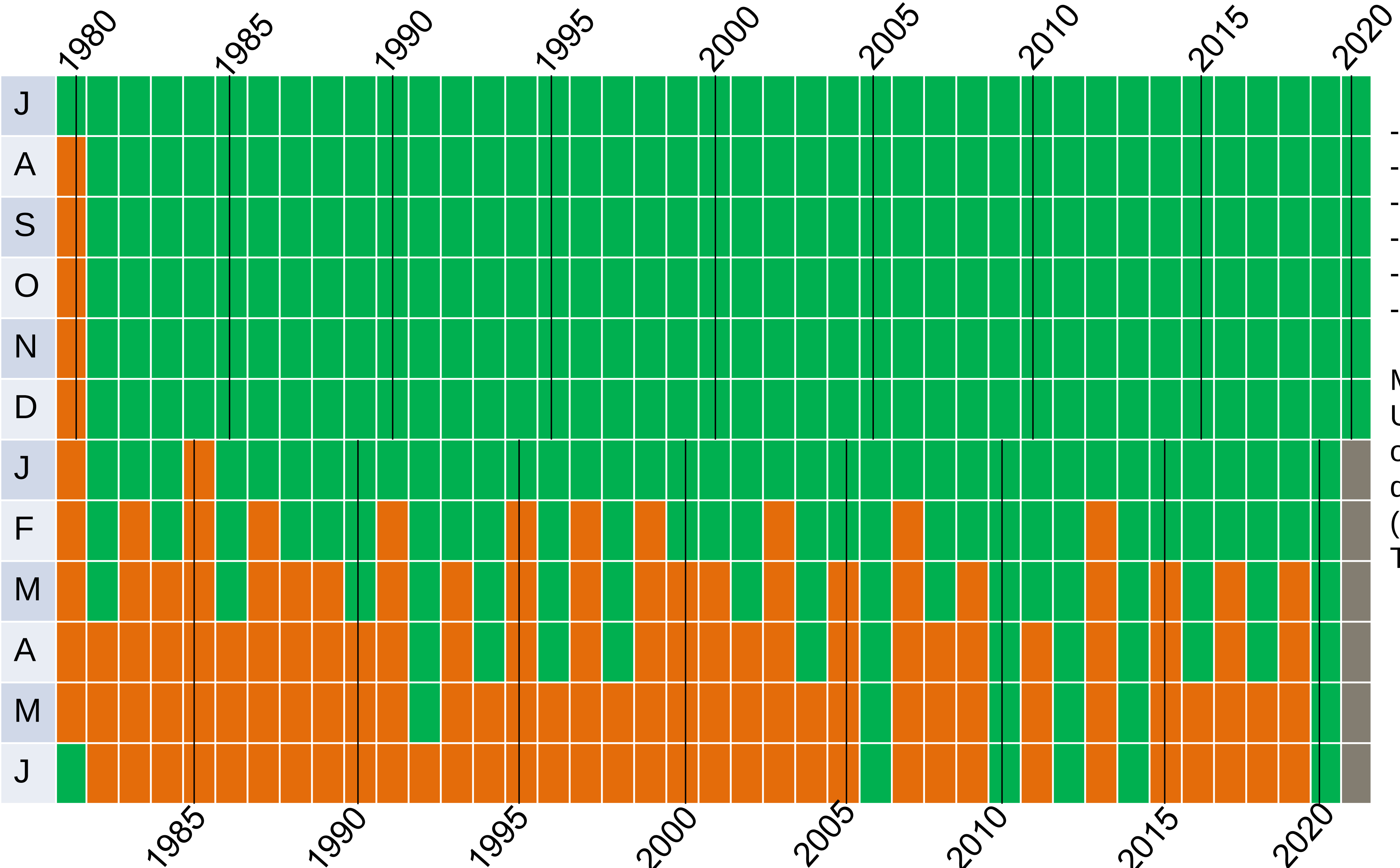
Product algorithm and accuracy

ERA5 reanalysis
- Coupled land-atmosphere model (HTESSEL in IFS)
- Coupled assimilation: 4D-Var atmosphere and 2D optimal interpolation snow data assimilation,
- Input observations: in situ snow depth (SYNOP, 1957-2021), and IMS snow cover from February 2004,
- Resolution 31km (native TL639), available 25km 1950-1978, native grid since 1979 until present

ERA5-Land
- Uncoupled model (HTESSEL), forced by ERA5
- No data assimilation
- No input observations
- Resolution 9km (native Tco1279), available 0.1 degrees, from 1982 to present

ERA5-Snow stand-alone reanalysis
- Coupled land-atmosphere model (HTESSEL in IFS)
- Uncoupled assimilation: 2D optimal interpolation snow data assimilation, forced by ERA5 atmosphere
- Input observations: in situ snow depth (SYNOP, 1980-2020)
- Resolution 31 km (TL639), period 1980-2020.

Product highlights: ERA5-snow production



- Streams of 1 year
- 42 streams 1980-2020
- Initialised 1 July each year
- 2D-OI snow assimilation
- SYNOP observations
- Completed: end of Feb 21

Motivation:
Use consistent snow observing system to avoid discontinuous snow in 2004 (see Zsoter et al. ECMWF TM 2020)

Product Summary Information ERA5 / ERA5-Land / ERA5-Snow

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Product name	ERA5 / ERA5-Land / ERA5-Snow
Satellite/Sensor/Algorithm	Atmospheric Reanalysis / Land surface Model / Land surface Reanalysis
Retrieval / Assimilation	Coupled assimilation / No assimilation / Stand alone land assimilation
Snow Parameter*	SWE (plus FSC diagnostic using snow density)
Spatial Coverage	Global
Map Projection / Grid	Gaussian reduced / Octahedral reduced Gaussian / Gaussian reduced
Pixel spacing	31 km / 9 km / 31 km
Temporal Coverage	N/A
Temporal Frequency	Hourly / hourly / 6-hourly
Accuracy Parameter **	Background error of snow depth
Accuracy Information ***	0.03 m (snow depth)
Webpage	https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5
Contact Point:	Hans.Hersbach@ecmwf.int / Joaquin.Munoz@ecmwf.int / Patricia.Rosnay@ecmwf.int
References	Hersbach et a. QJRMS 2020 / In prep / in prep