ASSESSMENT OF NORTHERN HEMISPHERE SWE DATASETS IN THE ESA SNOWPEX INITIATIVE

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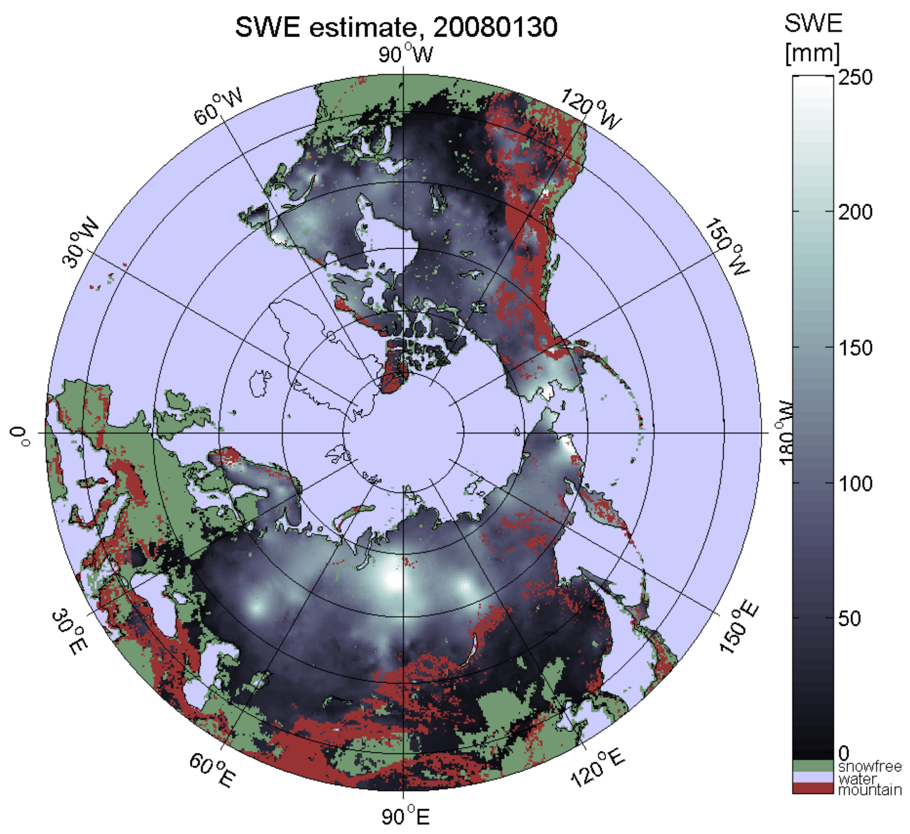
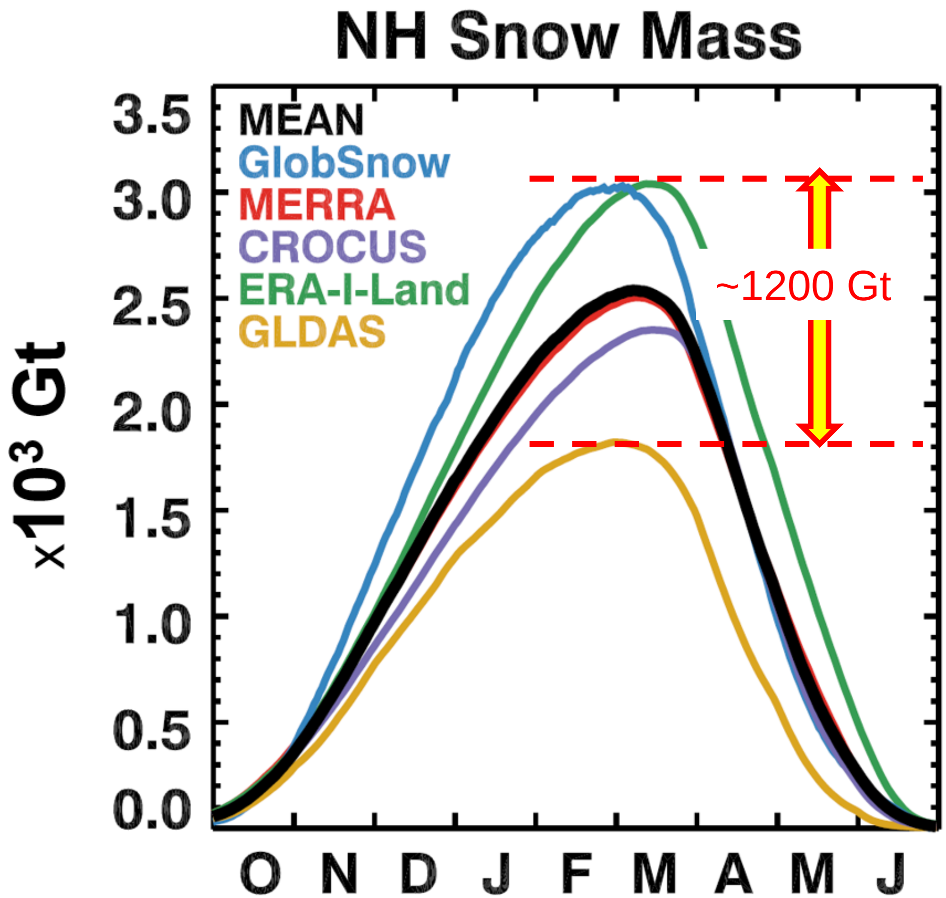
Uncertainty in NH Seasonal Snow mass

Spread in NH snow mass between **model-based** and **Satellite-based** estimates!



"Satellite-based" GlobSnow SWE estimate



Models vs. "Satellite-based" data

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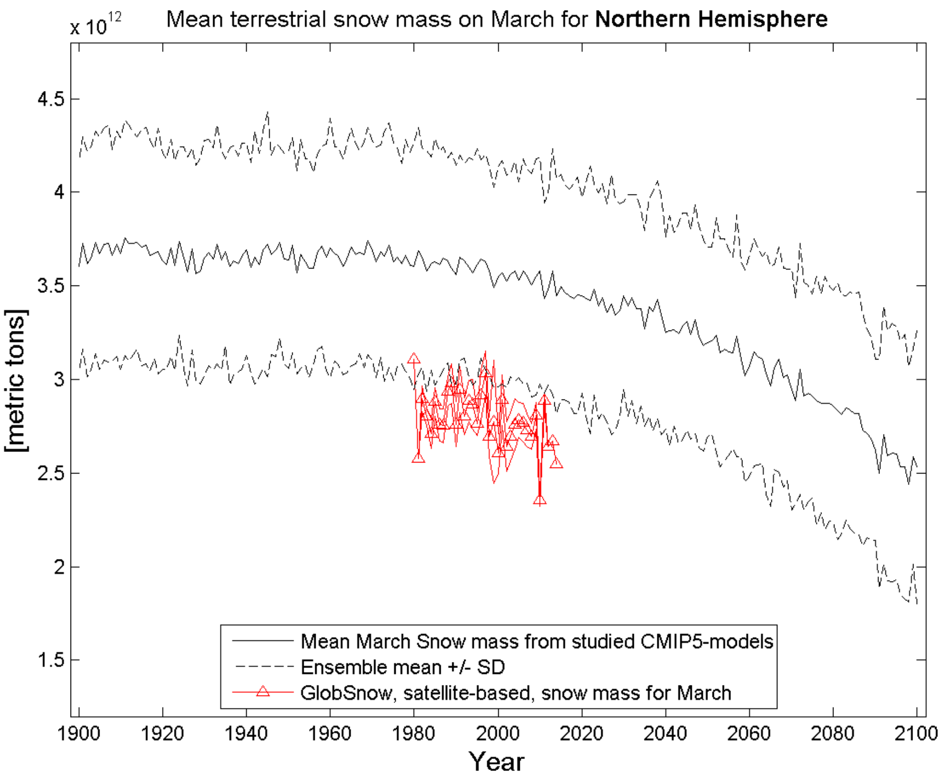
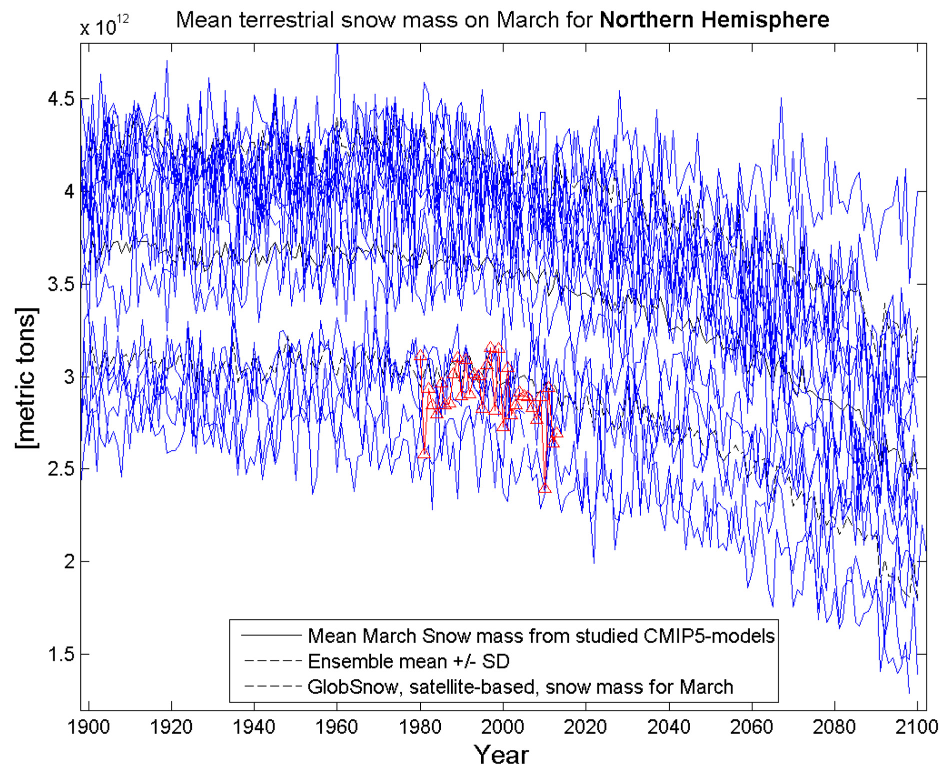
GlobSnow ensemble vs. ensemble historical & RCP8.5 ”forecast”
March & April: 16 CMIP5 models

- Significant over-estimation of spring-time snow mass in CMIP5 model simulations
- CMIP5: Historical + RCP8.5 forecasts





GlobSnow mean: 2900 Gt
CMIP5 mean: 3600 Gt (~25% over-estimation)

March spread in CMIP5: **2600 – 4300** Gt

SnowPEx SWE Datasets (Oper., NH-domain)

Dataset	Method	Ancillary/ Forcing Data	Resolution	Time Series	Reference
GlobSnow	Passive microwave + in situ	Weather station snow depth measurements	25 km	1979-2015	Takala et al (2011)
NASA AMSR-E standard	Standalone passive microwave		25 km	2002-2011	Kelly (2009)
NASA AMSR-E prototype	Microwave + ground station climatology	Weather station snow depth climatology	25 km	2002-2011	TBD
ERAint-Land	HTESSEL land surface model	ERA-interim	0.75° x 0.75°	1981-2010	Balsamo et al (2013)
MERRA	Catchment land surface model	MERRA	0.5° x 0.67°	1981-2010	Rienecker et al (2011)
Crocus	ISBA land surface + Crocus snow model	ERA-interim	1° x 1°	1981-2010	Brun et al (2013)
GLDAS-2	Noah 3.3 land surface model	Princeton Met.	1° x 1°	1981-2010	Rodell et al (2004)

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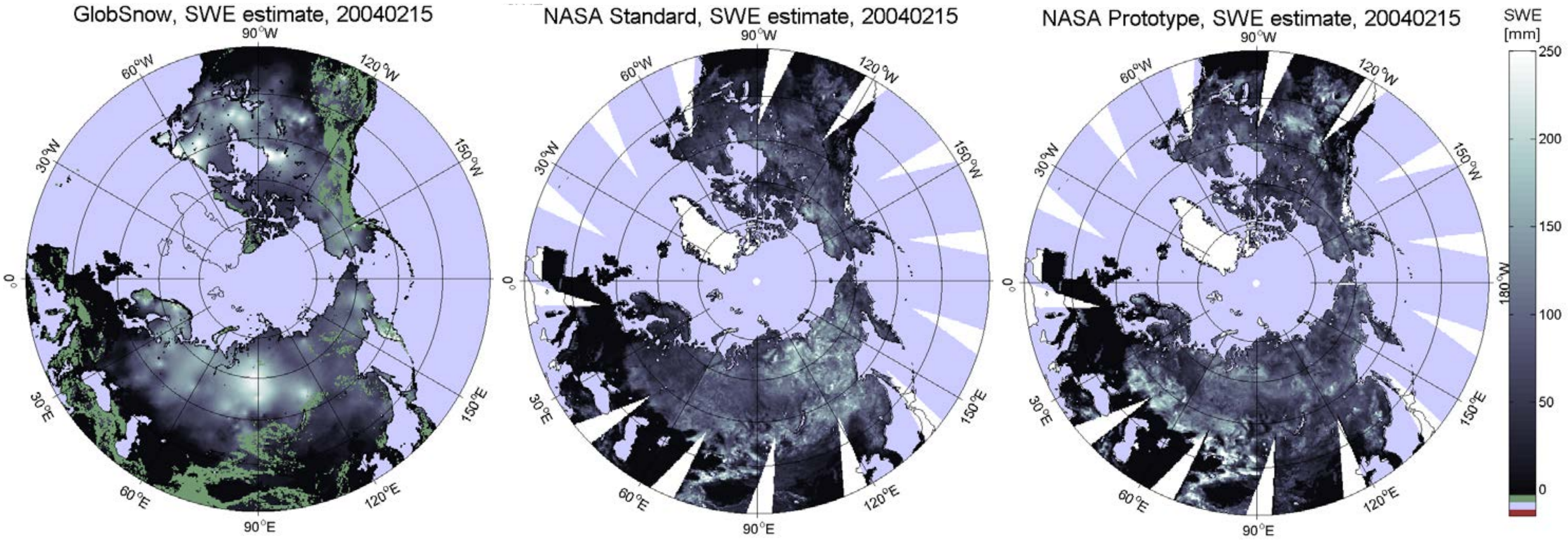
GlobSnow-2, NASA Standard, AMSR-e Prototype SWE "Quicklooks"



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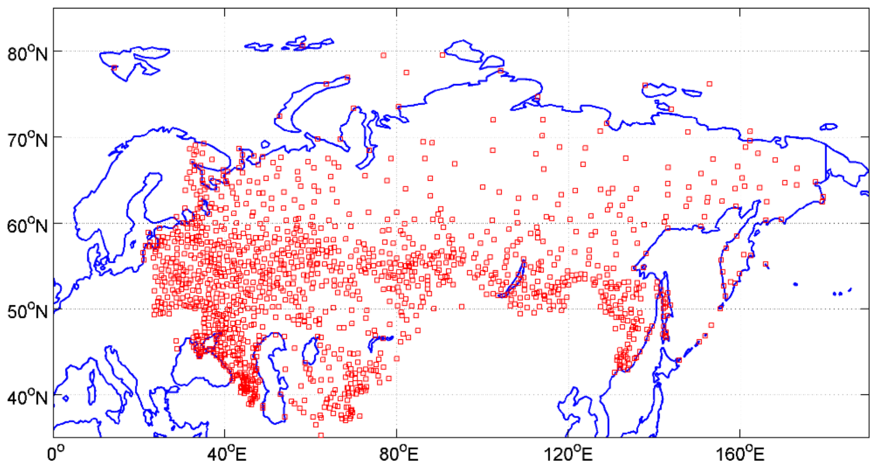
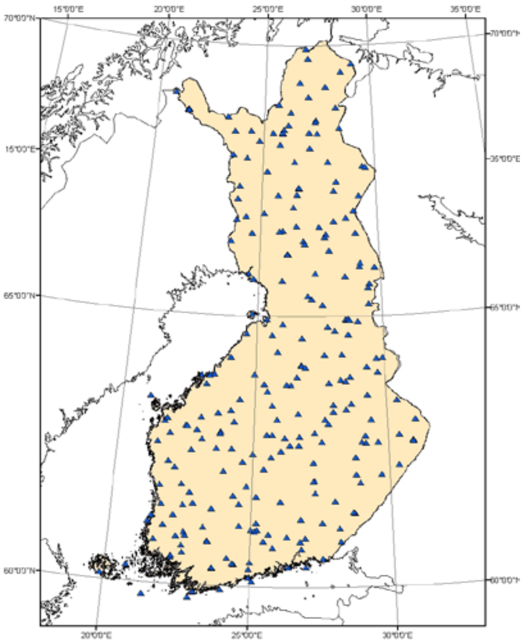
Reference data – snow courses & transects

- Russia, a total of 1346 snow transects
- Vast geographical domain with diverse conditions

The snow transect reference data from Russia



- Finland, 100+ national snow courses



- Russia: years 1966-2016, 1-2km snow transects, Northern Eurasia
- Finland: years 1979-2017, 4km snow courses, Northern boreal forest

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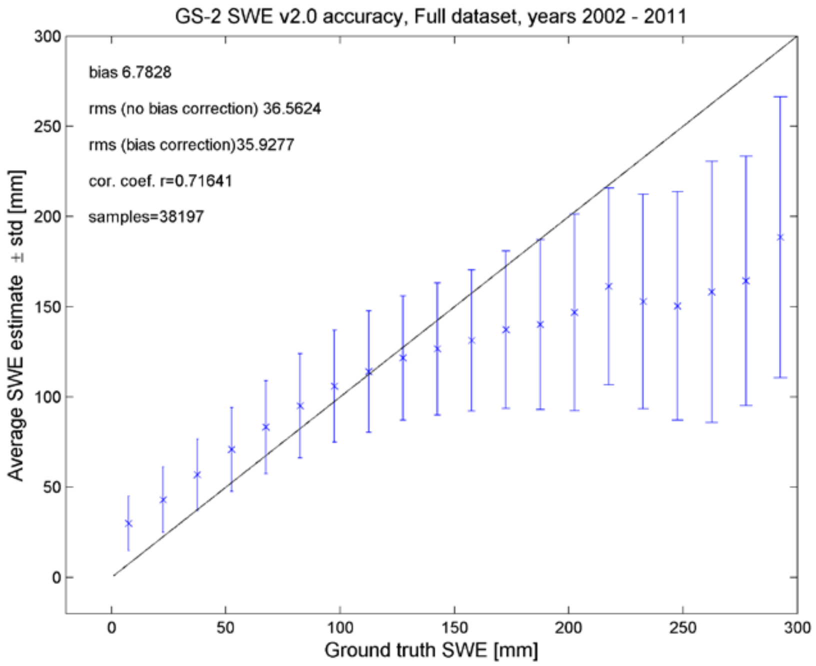
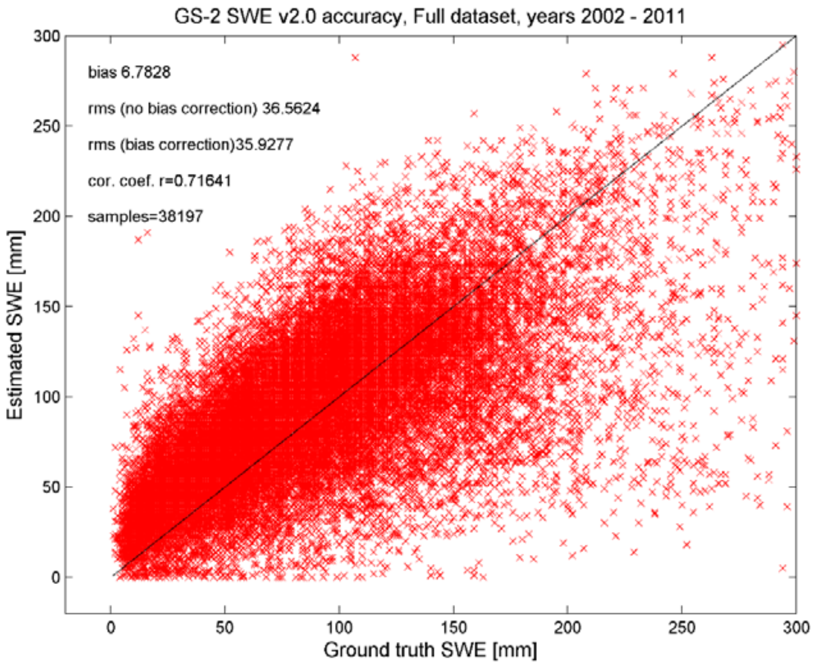
GlobSnow-2 SWE vs. RIHMI WDC (2002-2011)

38197 Coinciding samples of GlobSnow, NASA Standard and NASA prototype SWE

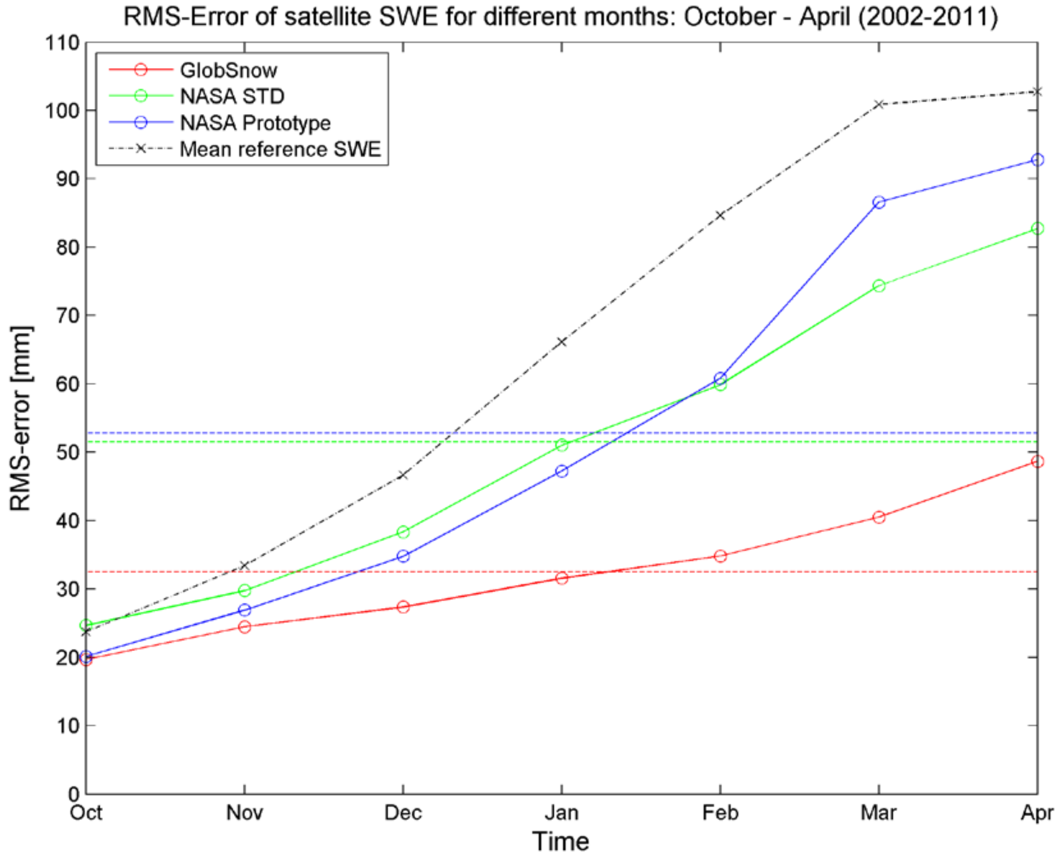
Evaluations for the samples available in all 3 products!





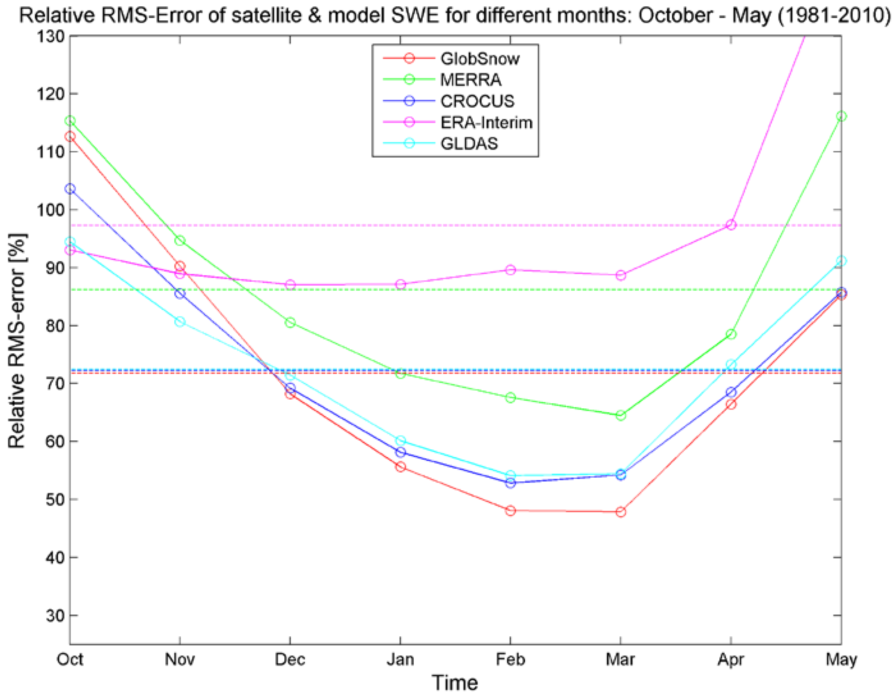
”Blended product” = combines satellite and ground-based WS-data

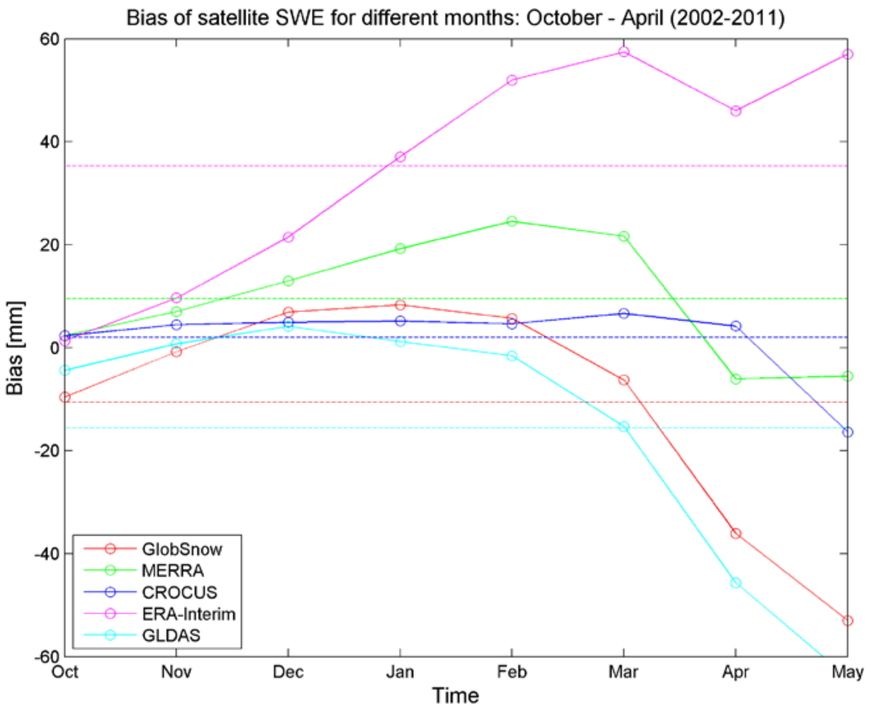
SWE analysis on a monthly basis, RMSE



- Differences increase towards the end of the snow accumulation season

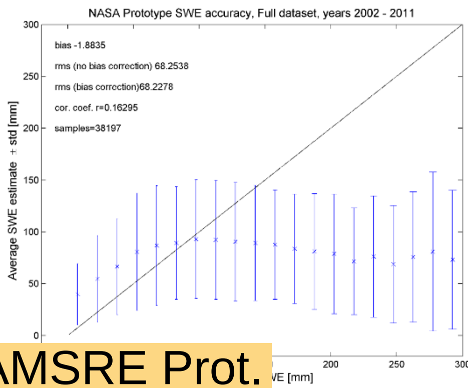
Monthly SWE Analysis: relative RMSE & bias



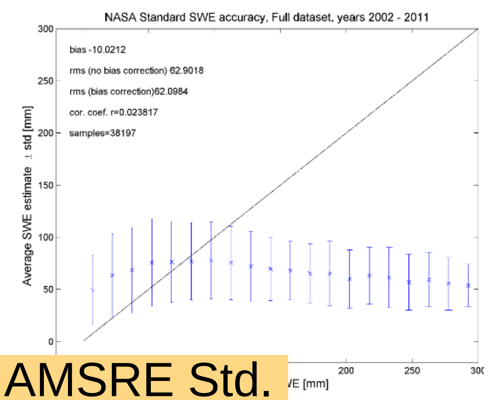


- Oct/May only ~3k samples, compared to 20k-40k for other months (1981-2010)

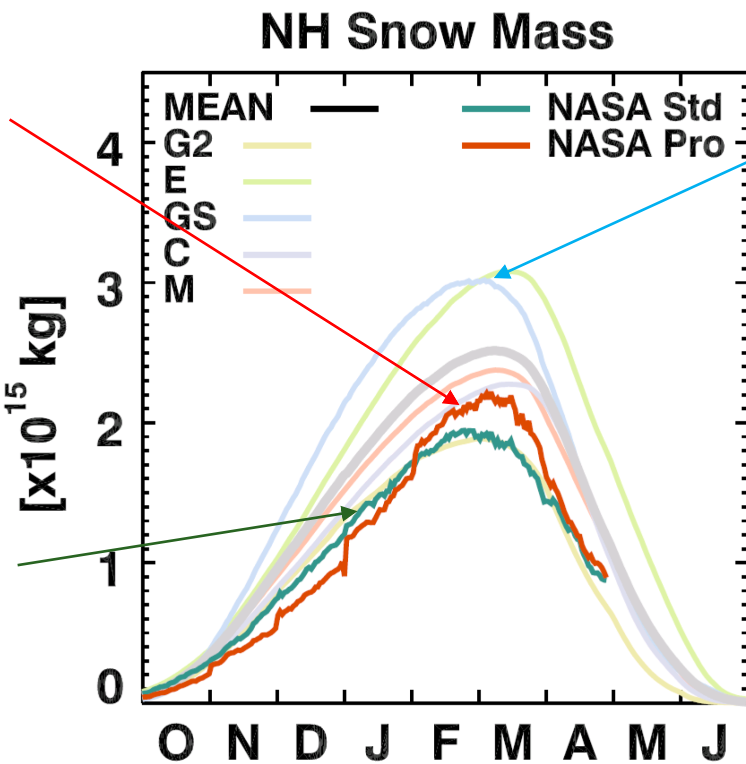
Overview: Satellite-based SWE datasets

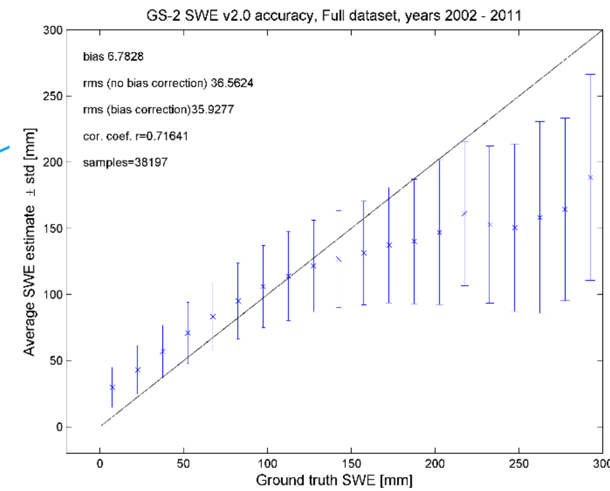


AMSRE Prot.



AMSRE Std.





GlobSnow

Observed under-estimation of NASA SWE products due to high negative bias with deep snow. Total snow estimates of GlobSnow for NH are more accurate.

Overview – SWE products (satellite & model-based)

- **Assessed for an uniform time period, ranked by retrieval performance (RMSE)**
- Time period 2002-2010 & 1981-2010, Russian snow course data as reference

Datasets	Dataset availability	Retrieval performance (RMSE) 2002-2010	Bias 2002-2010	Retrieval performance (RMSE) 1981-2010	Bias 1981-2010
GlobSnow v2.0	**1979-2015**	**42.6 mm**	**-3.8 mm**	44.9 mm	-4.3 mm
CROCUS-Era-Interim	**1981-2010**	**45.8 mm**	**+1.1 mm**	48.0 mm	+4.7 mm
GLDAS2.0-Noah	**1981-2010**	**48.0 mm**	**-8.4 mm**	49.5 mm	-10.8 mm
MERRA (Standard)	**1981-2010**	**54.9 mm**	**+12.9 mm**	57.9 mm	+15.2 mm
ERA-Interim (ERA-Land)	**1981-2010**	**67.3 mm**	**+35.4 mm**	74.7 mm	+42.4 mm
NASA Standard	**2002-2011**	**67.4 mm**	**-24.3 mm**	-	-
NASA Prototype	**2002-2011**	**72.4 mm**	**-19.9 mm**	-	-

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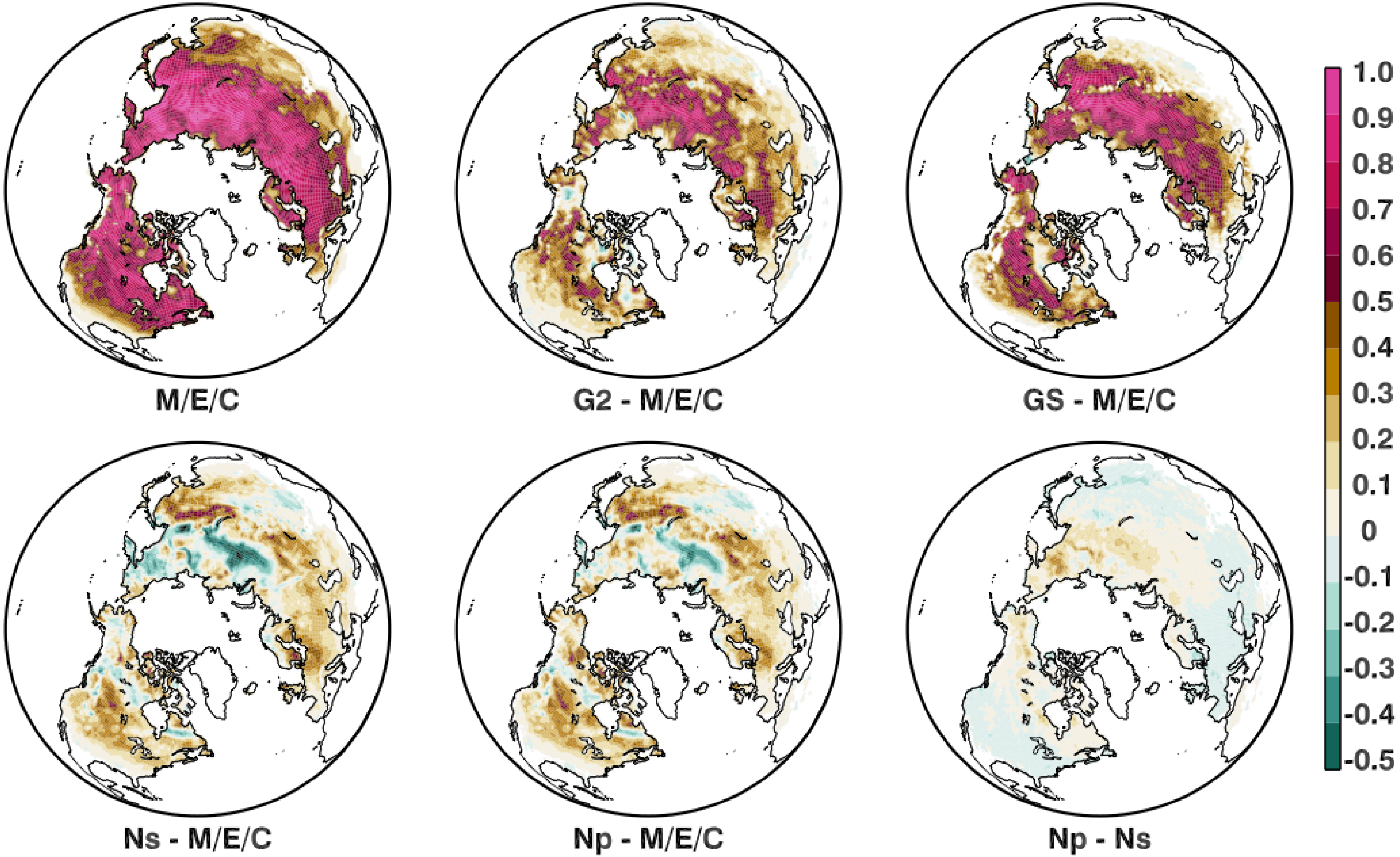
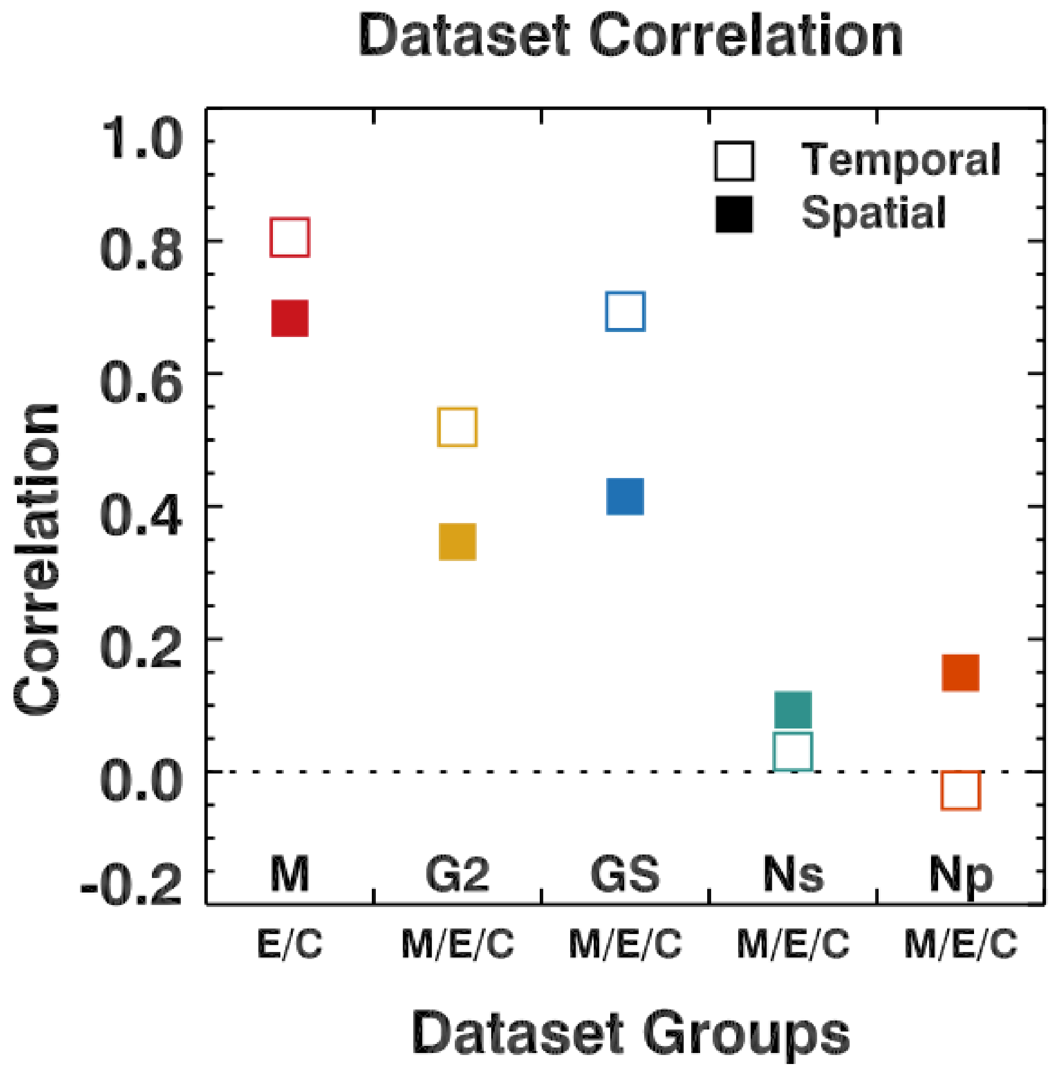
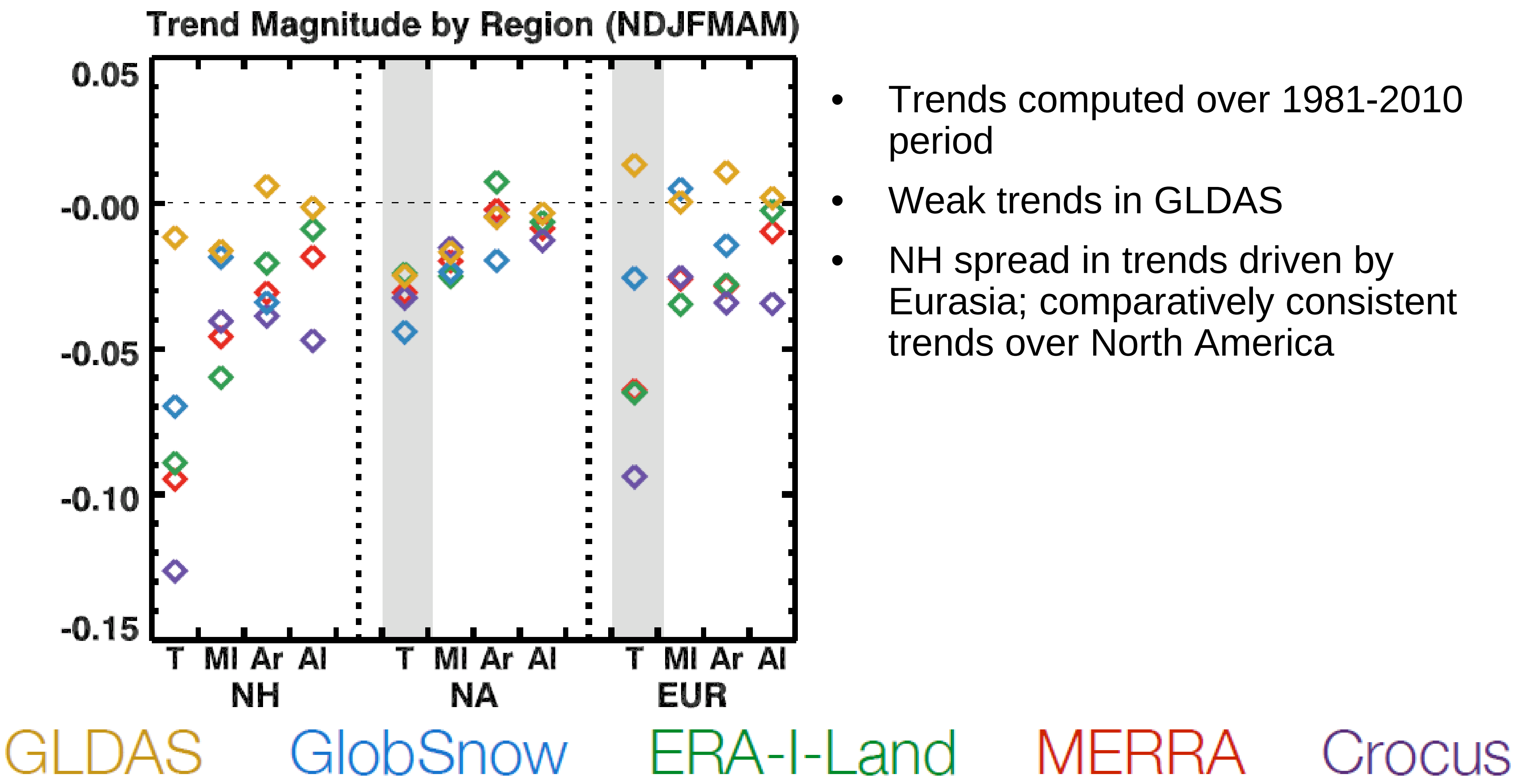
Anomaly Correlation



Comparison of Anomalies



Trends



- Trends computed over 1981-2010 period
- Weak trends in GLDAS
- NH spread in trends driven by Eurasia; comparatively consistent trends over North America

Constraining SWE products using optical SE data

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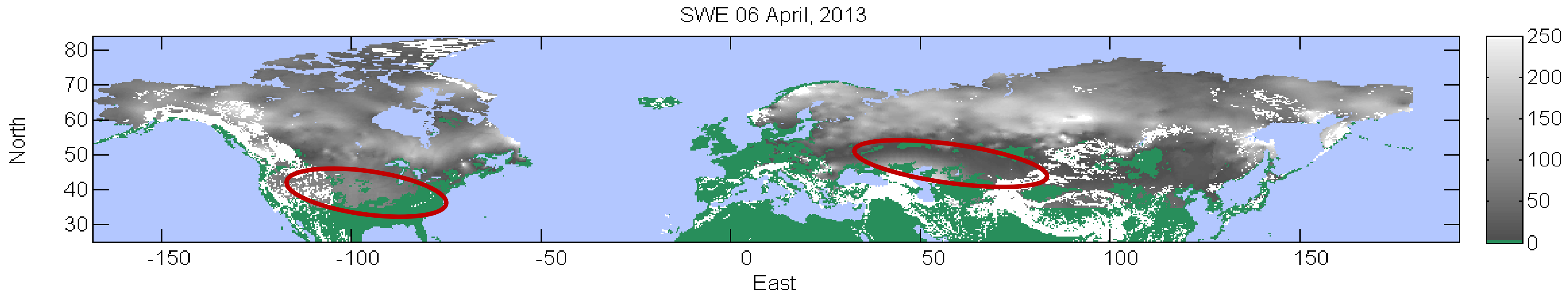
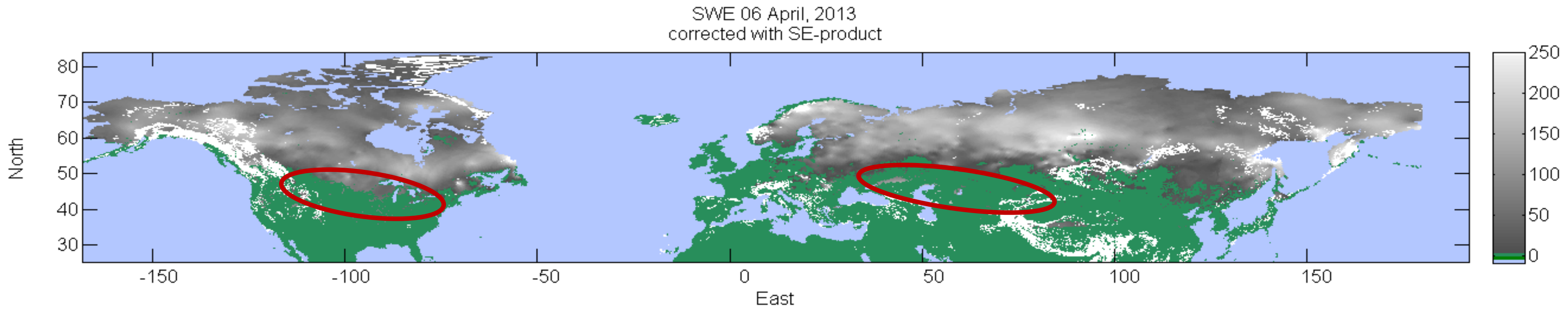
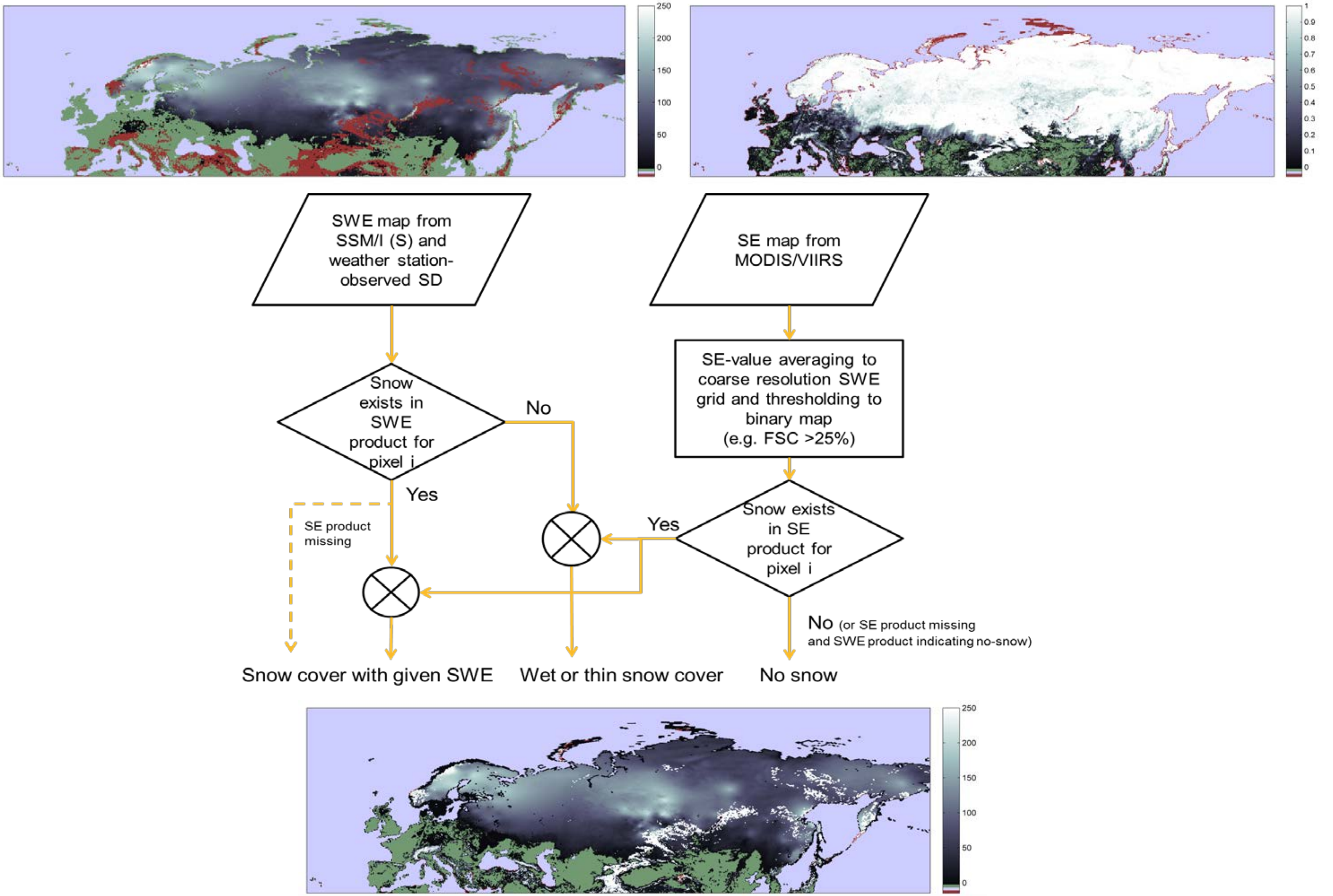
Fusion of GlobSnow SE and SWE

GlobSnow SWE NRT-product has difficulties in detecting snow line during spring melt season -> snow line identification from SE-product





Fusion with optical data (***GlobSnow SCAmod VIIRS***)
-> more realistic snow line during the melt season

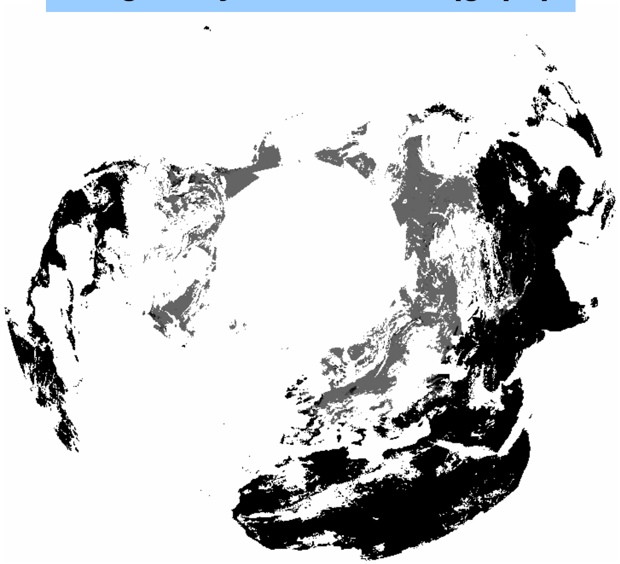


250
200
150
100
50
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
SWE map from SSM/I (S) and weather station-observed SD
SE map from MODIS/VIIRS
SE-value averaging to coarse resolution SWE grid and thresholding to binary map (e.g. FSC >25%)
Snow exists in SWE product for pixel i
No
Yes
SE product missing
Snow exists in SE product for pixel i
Yes
No (or SE product missing and SWE product indicating no-snow)
Snow cover with given SWE
Wet or thin snow cover
No snow
250
200
150
100
50
0

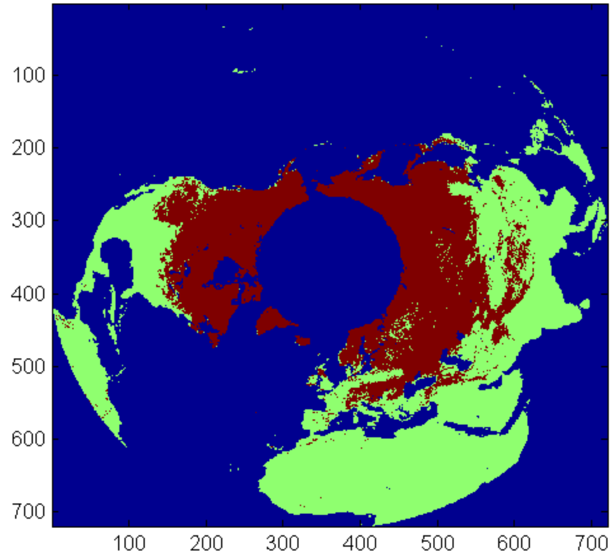
JXAM5 daily (5km) FSC -> cumulative daily (25km) SE

- SE data from 1978-2016 acquired from JAXA and converted to 25km EASE-grid
  - 1978-2000 from AVHRR; 2001-2016 from MODIS
    - 2001-2008 (AVHRR & MODIS overlap) checked for consistency → OK
- Daily FSC data were combined into a cumulative daily SE mask, using 25% cutoff value
- GlobSnow FPS SWE masked (corrected) using daily composite SE-data

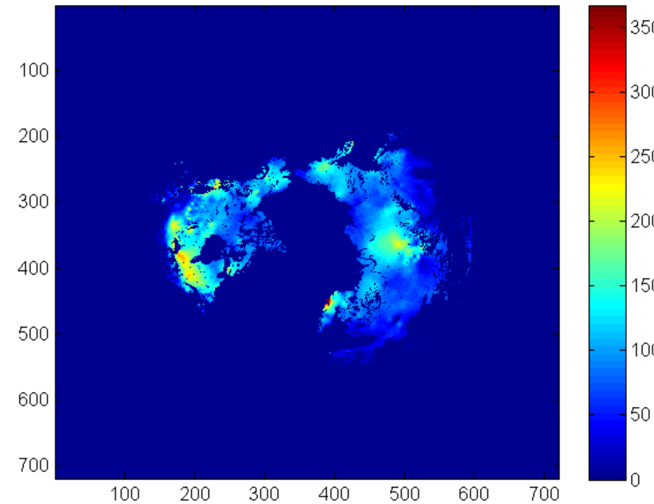
Single day JXAM5 FSC (gaps)



Cumulative SE map (no gaps)



SE masked SWE product



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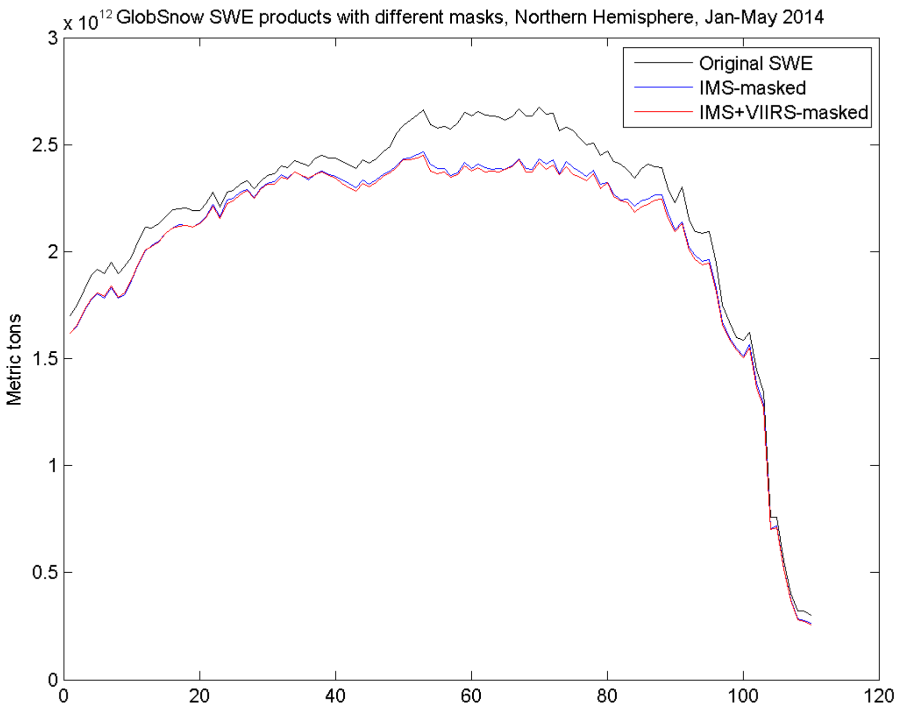
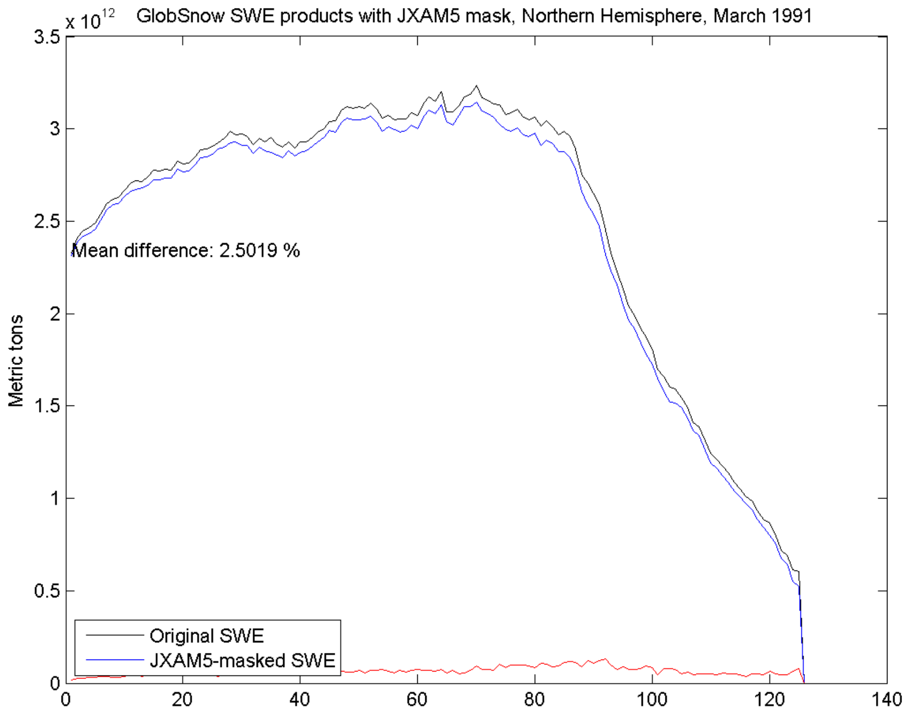
JXAM5 SE-masked GlobSnow SWE - Spring

- IMS+VIIRS-masked **NRT SWE** product shows significantly higher decrease in HN snow mass, than JXAM5 masked, **long term FPS** SWE data





IMS+VIIRS masking -> 8,0% decrease in mass

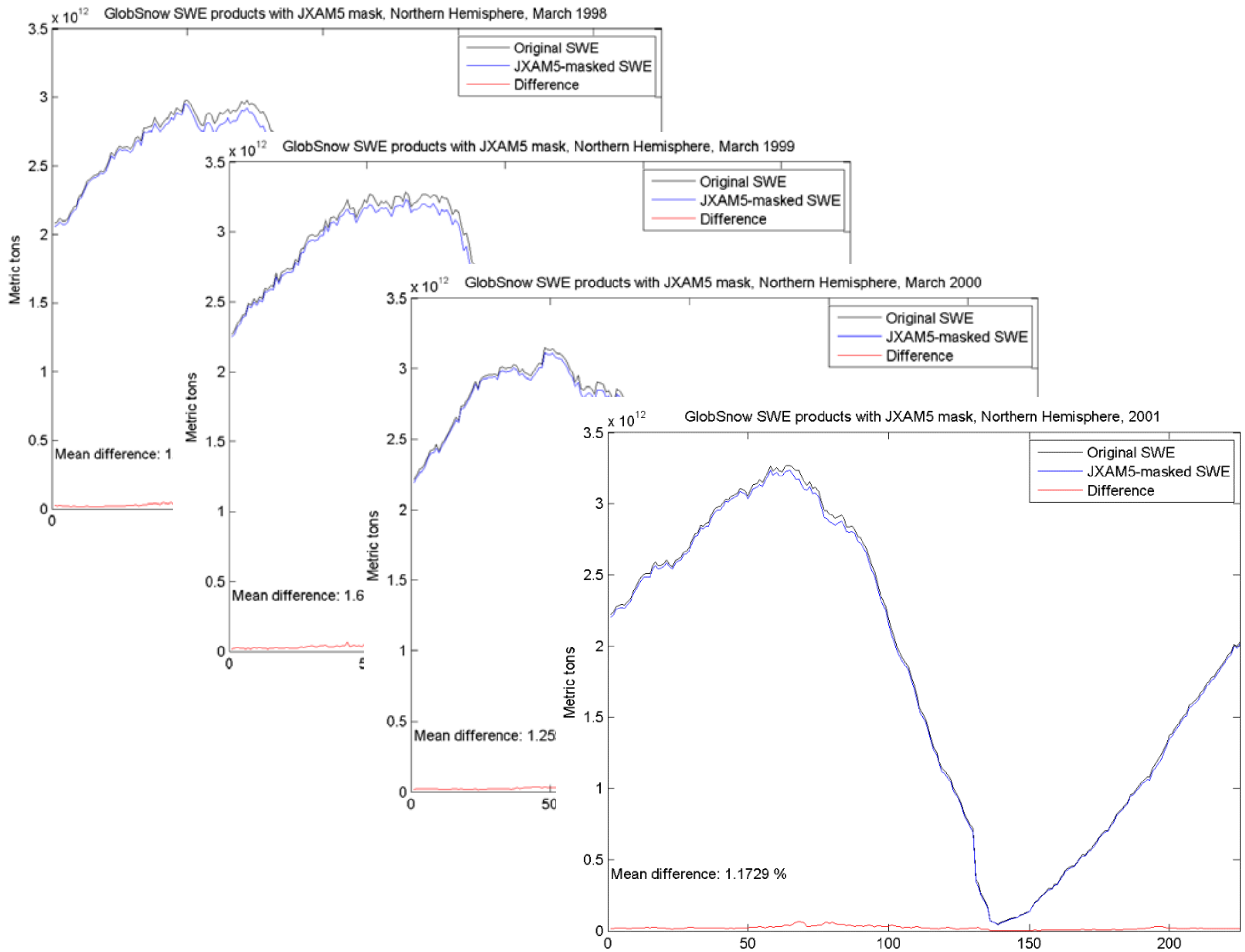
JXAM5 -> 2,5% decrease in mass (<u>at most</u>)

Original assessment was carried out for NRT SWE product with tendency to overestimate spring-time SWE! <u>Long-term SWE FPS has an improved snow line, as can be seen!</u>

Average changes in snow mass (constaining SWE with SE data)

Average changes: (1982-2016)

- Jan.-March: -1.37 %
- March: -1.85 %
- March-May: -2.24 %
- Autumn: -1.14 %
- Whole year: -1.57 %



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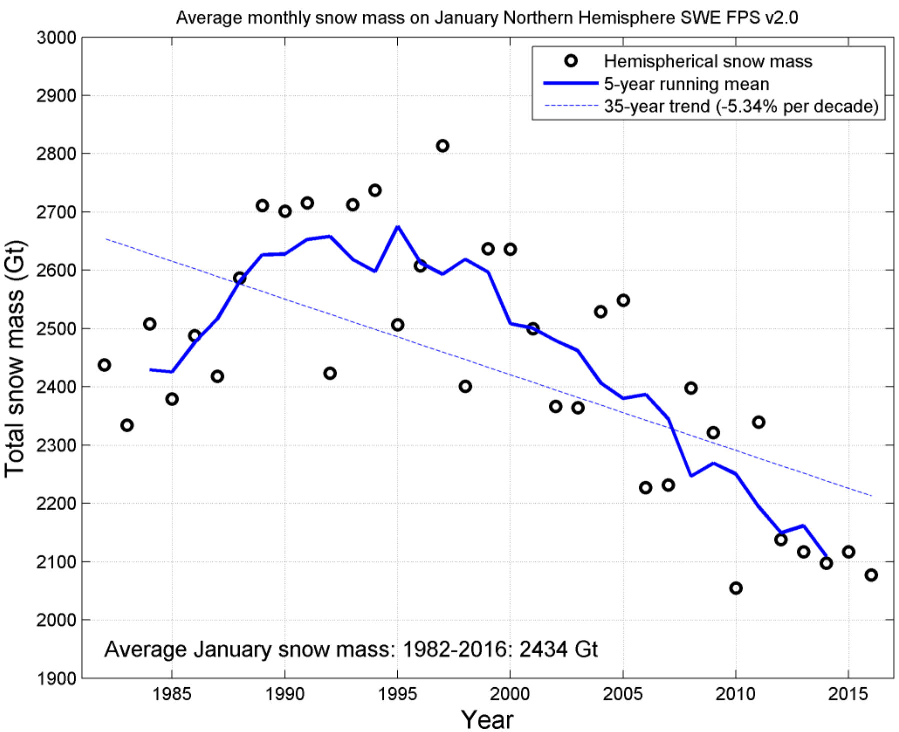
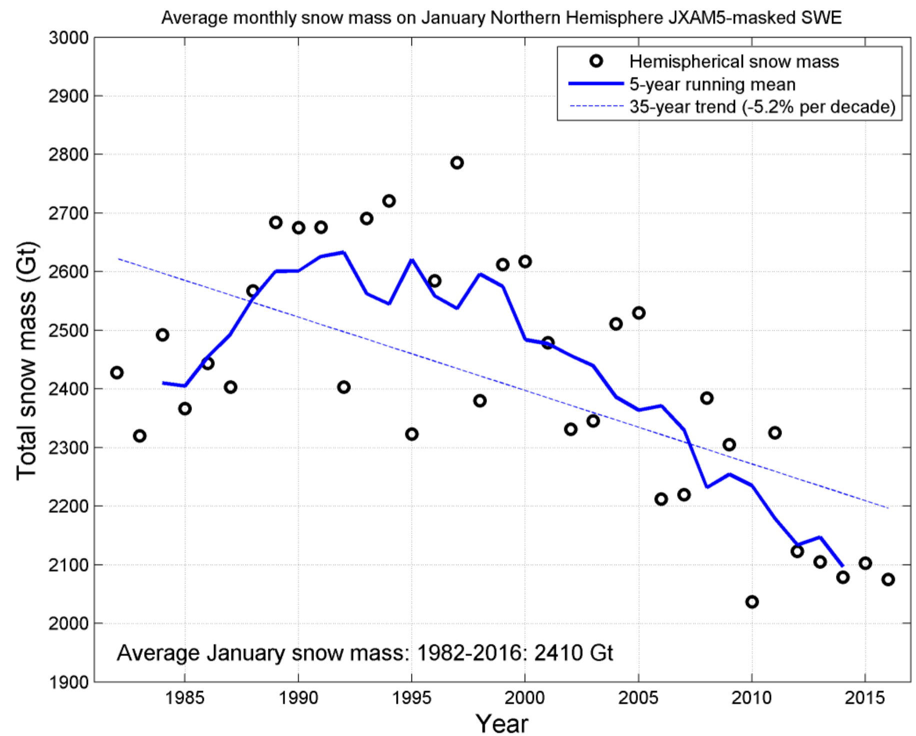
JXAM5 SE–masked GS SWE trends (1982 – 2016)
January -> trends are practically the same





-5.3%

-5.2%

Trends are practically the same

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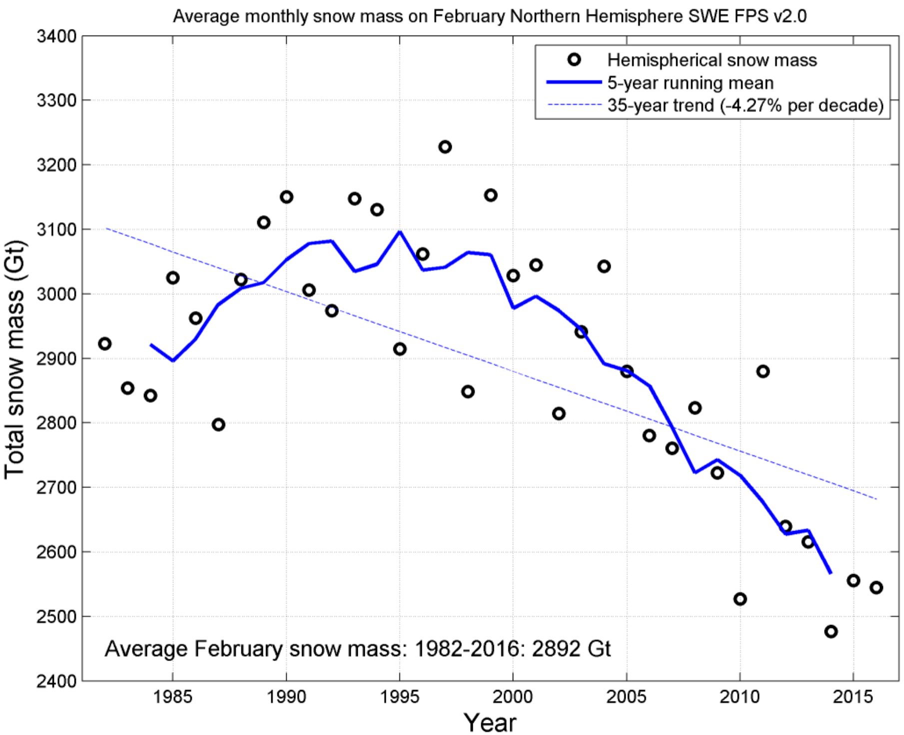
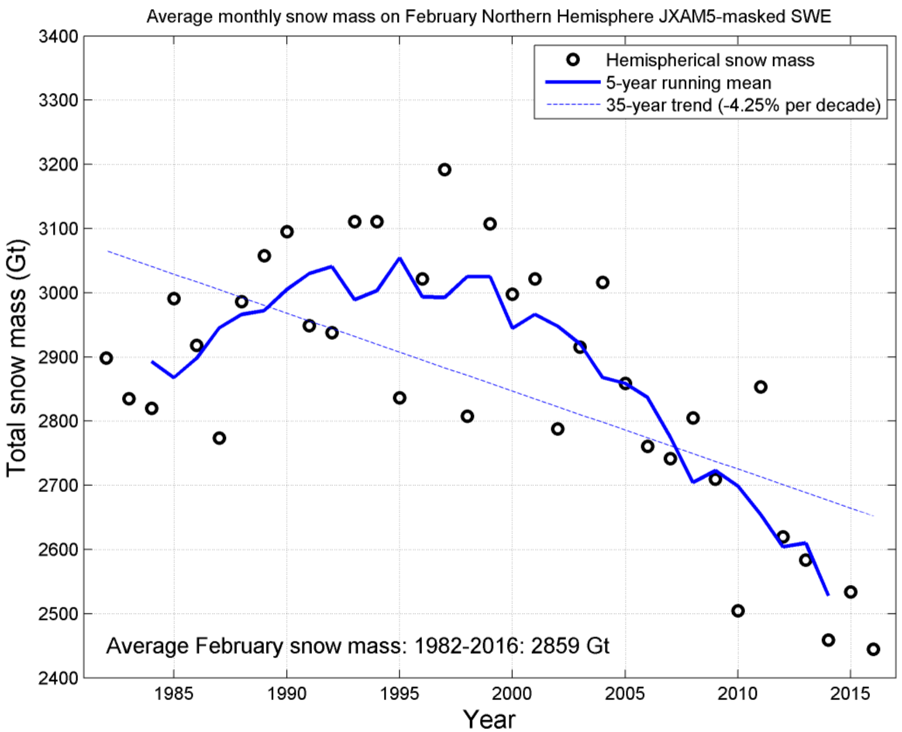
JXAM5 SE–masked GS SWE trends (1982 – 2016)
February -> trends are practically the same





-4.3%

-4.3%

Trends are practically the same

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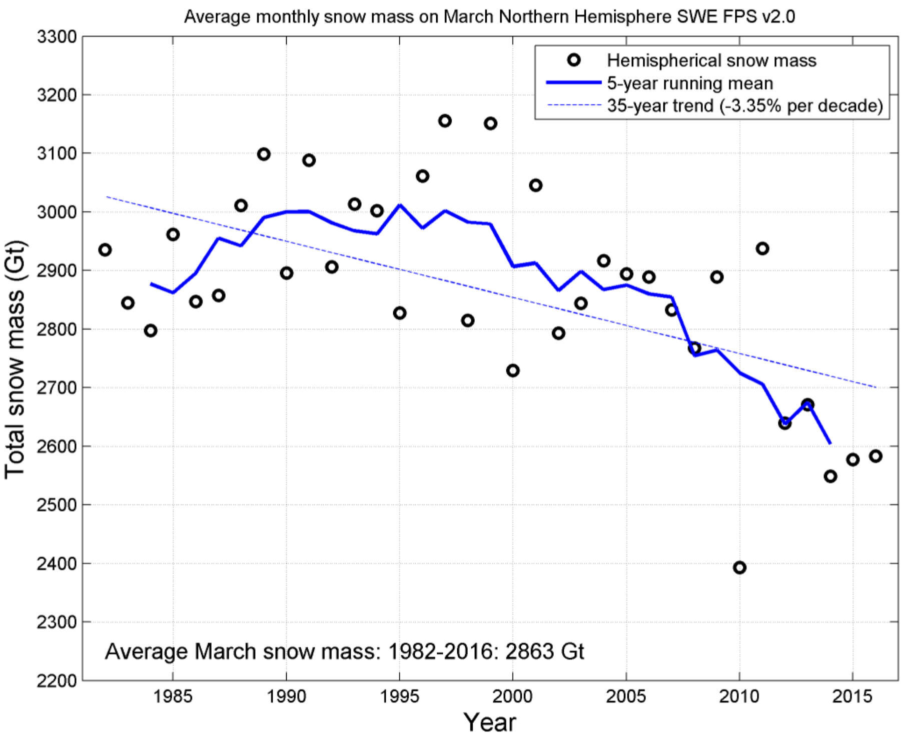
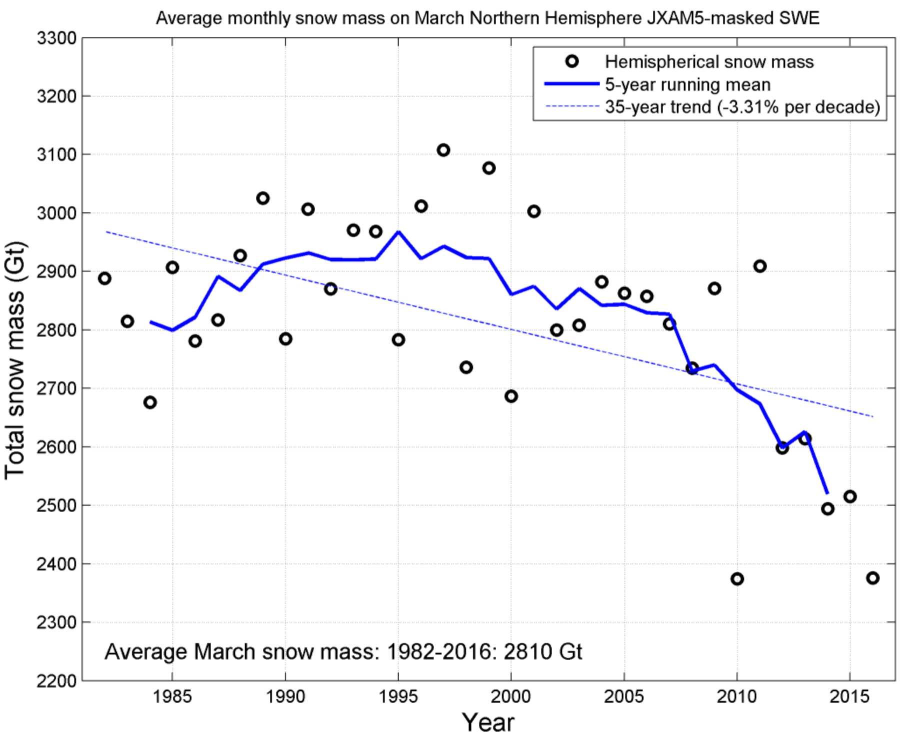
JXAM5 SE–masked GS SWE trends (1982 – 2016)

March -> trends are practically the same



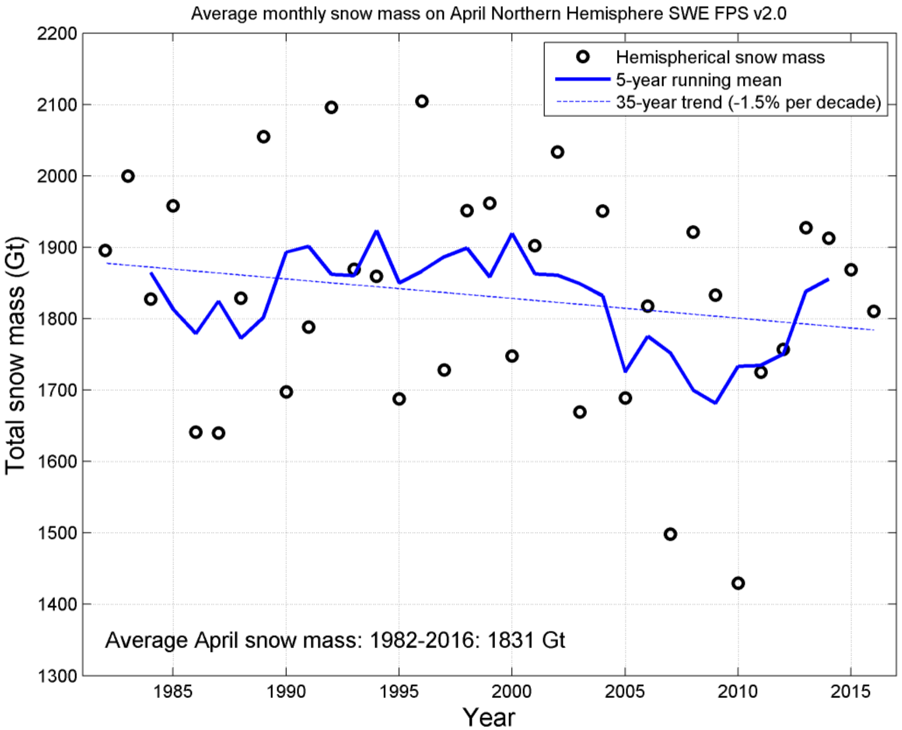


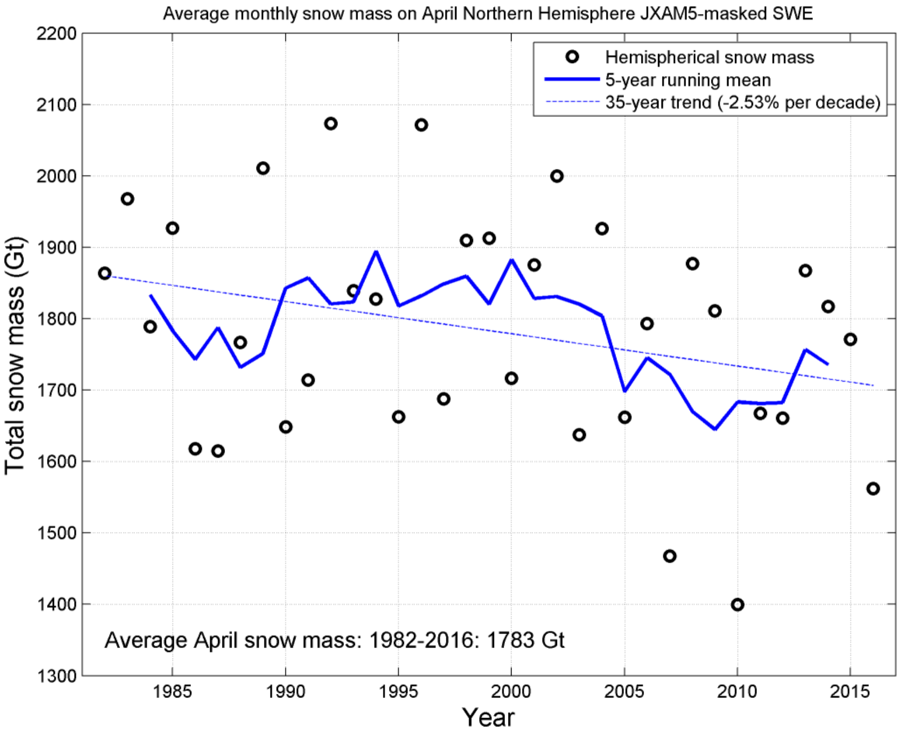
-3.4%

-3.3%

Trends are practically the same

JXAM5 SE–masked GS SWE trends (1982 – 2016)
April -> trends are slightly increased in the SE-masked product





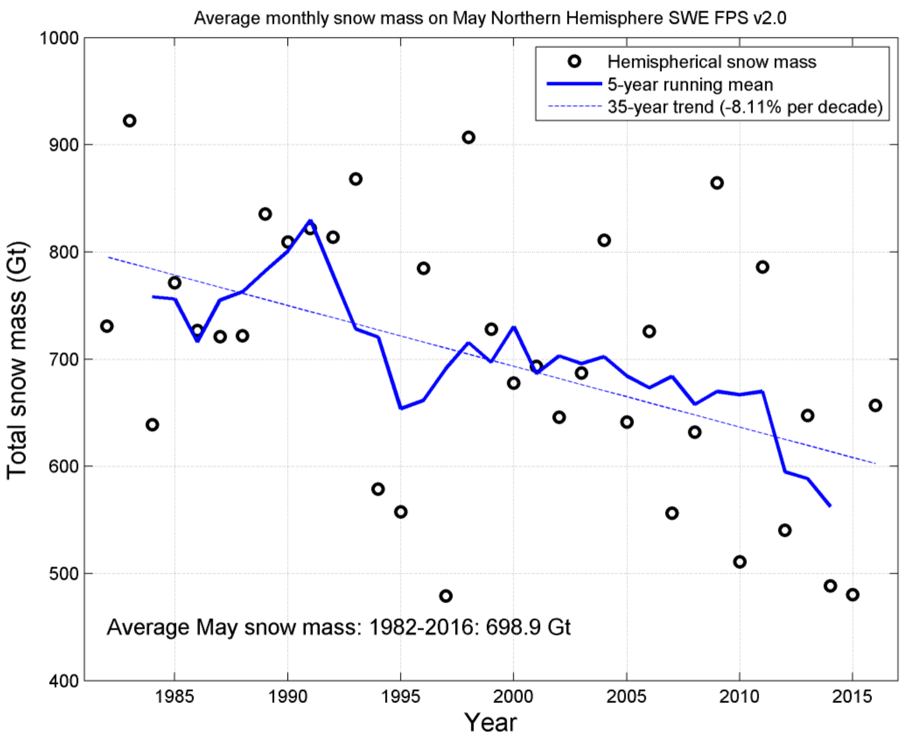
-1.5%

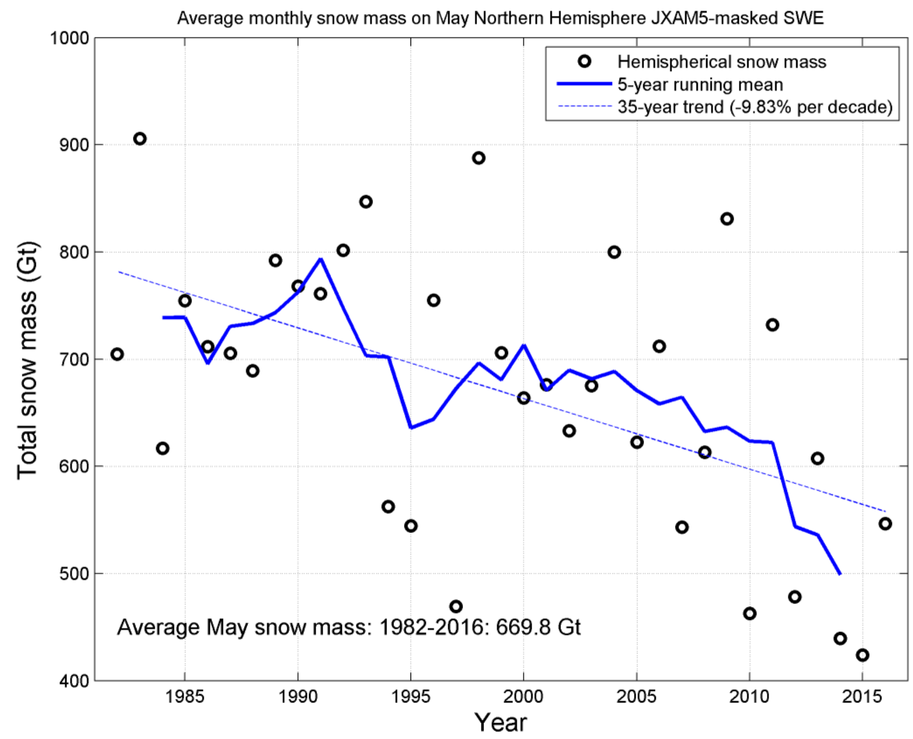
-2.5%

JXAM5-masked GlobSnow SWE
Shows an increased trend

JXAM5 SE–masked GS SWE trends (1982 – 2016)

May -> trends are slightly increased in the SE-masked product





-8.1%

-9.8%

JXAM5-masked GlobSnow SWE Shows an increased trend

Assessment of SE trends using SWE data

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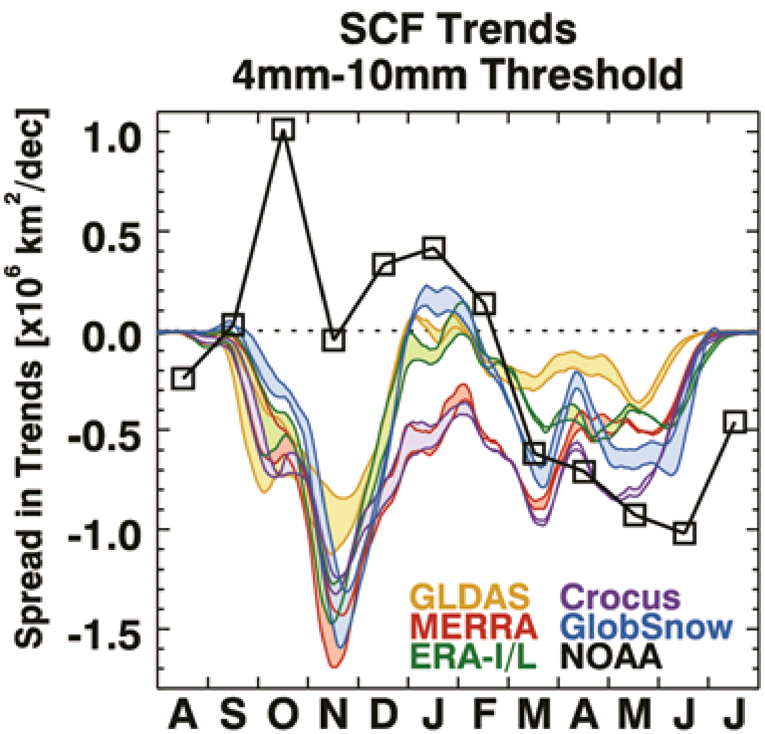
EC

- Trend analysis:

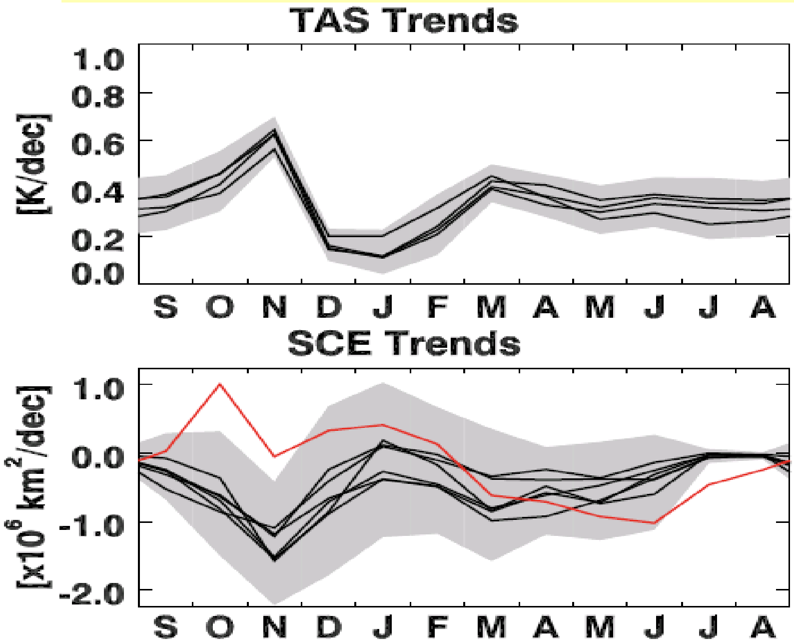
  -Integration of SCE and SWE products: SE used to limit SWE (GlobSnow & JXAM5)

  -SWE products converted to SCE, 1981-2010; monthly spatial trend maps at 1x1 deg; temporal trend statistics.

  -Snow Extent trends from various SWE datasets vs. NOAA_CDR long term trend!



Monthly NH surface temperature trends from CRU, NCDC, GISS and NCEP2m



NOAA-CDR is an outlier, esp. Oct/Nov

Monthly NH SCE trends from MERRA, ERA-I-Land, Crocus, GLDAS-2, Brown, GlobSnow, and NOAA-CDR

Conclusions on NH SE constrained SWE

- Constraining SWE using optical SCE data results in a new more detailed assessment of volume changes for the NH over the satellite-era (1982-2016)

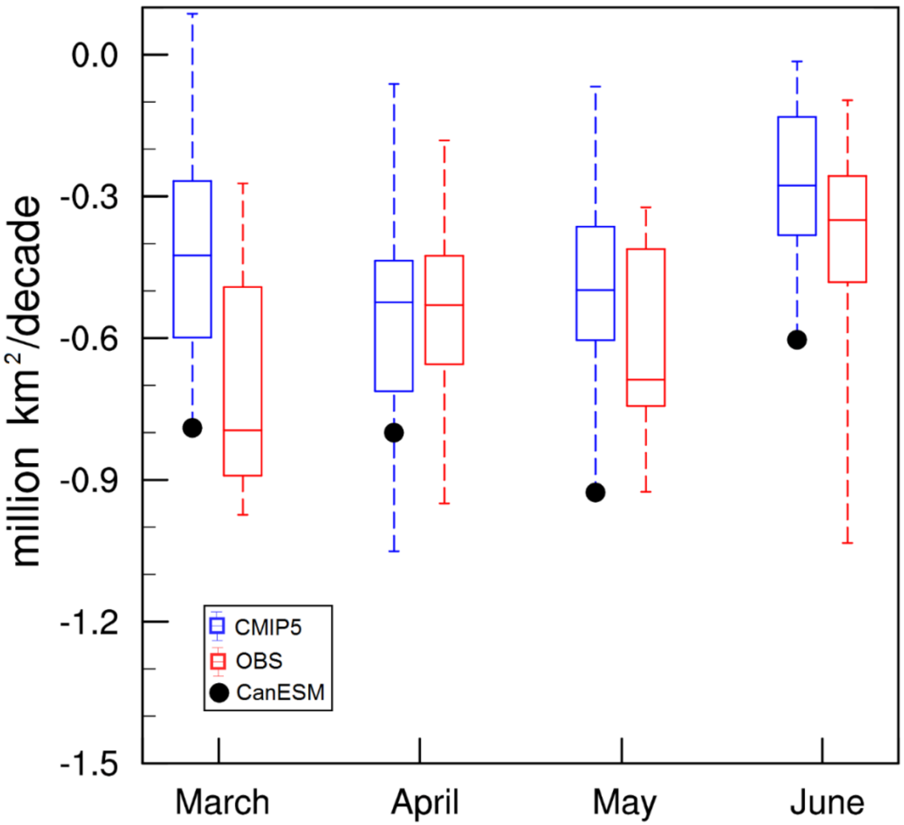
- The results show a significant decrease in hemispherical snow mass in the past 35 years (1982-2016), **May** showing a **-9.8% decrease per decade**
- Looking at the timeframe 1982-1999 and 2000-2016, there's an average decrease of -8.7% in the NH snow mass (individual months in the table – snow masses in gigatons)

	1980-1999	2000-2016	Decrease
January	2531	2281	-9,9%
February	2969	2742	-7,7%
March	2900	2717	-6,3%
April	1828	1736	-5,0%
May	721	615	-14,7%

Total amount of seasonal snow on Northern Hemisphere is clearly decreasing

SnowPEx SWE Conclusions

- There is considerable inter-dataset spread in Northern Hemisphere snow mass and snow cover extent derived from available terrestrial snow products.
- Skillful satellite retrievals require assimilation of weather station snow depth observations; land surface models are limited by cold season processes, precipitation forcing etc. In both cases, spatial resolution is a limitation.
- NH snow water trends are generally decreasing in magnitude.
- Snow water trends over Eurasia are generally more uncertain, especially in eastern Siberia.
- Analysis of multiple snow products has a major benefit for climate applications – model spread can be compared to observational spread.



Thackeray et al., in review