ESA DUE GlobSnow 2008- - 2014 A New Benchmark Product Set for Northern Hemisphere Snow Cover Information

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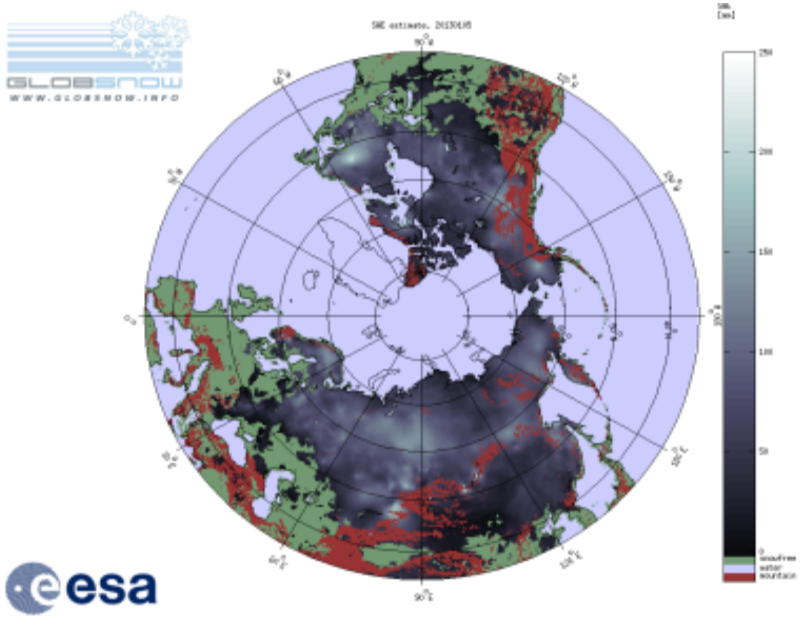
ESA DUE GlobSnow – Operational Snow monitoring of Northern Hemisphere, combined with long term climate records

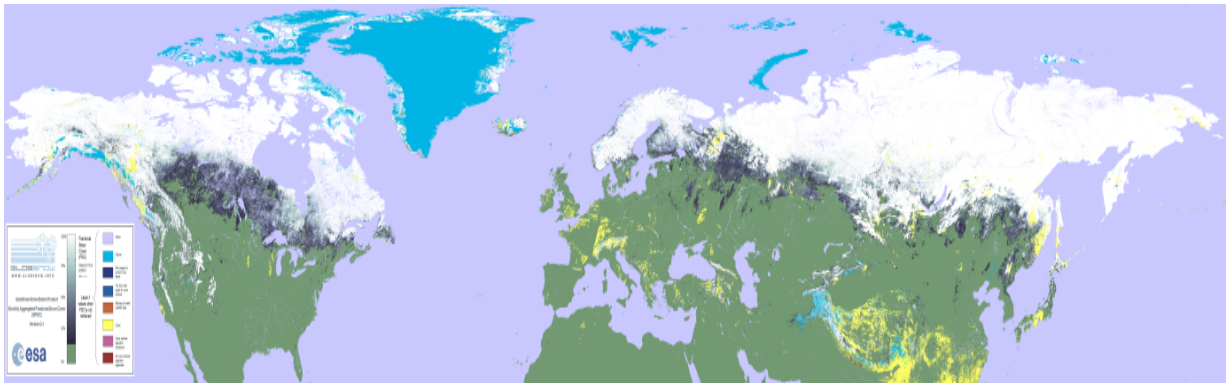
Snow Water Equivalent (SWE)

- 35 year-long CDR time-series on snow conditions of Northern Hemisphere (25x25 km grid)
- Passive microwave radiometer data combined with ground-based synoptic snow observations



Snow Extent (FSC)

- 15 years Snow Extent data record from ESA ATSR-2 (1995-) and AATSR (2002-2012) on a hemispherical scale.
- Methodology developed especially for forested regions
- **Suomi NPP VIIRS & Sentinel 3 SLSTR** for continuation



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ESA DUE GlobSnow-1/-2

• ESA DUE GlobSnow project: Production of novel hemispherical **snow extent** (SE) and **snow water equivalent** (SWE) climate data records.

• **Generation of long time-series employing FMI supercomputing facilities at Helsinki** (daily, weekly and monthly maps of SE and SWE for northern hemisphere) **+ NRT processing**

• Consortium: Finnish Meteorological Institute (FMI) with ENVEO IT GmbH (Austria), GAMMA Remote Sensing (Switzerland), Norwegian Computing Center, Finnish Environment Institute (SYKE), and Environment Canada (EC). + Univ. Bern, MeteoSwiss, ZAMG & Norut

• GlobSnow-1: 11/2008 – 04/2012 (3.5 years)
• GlobSnow-2: 05/2012 – 10/2014 (2.5 years)

• Details and products available at **www.globsnow.info**

ZAMG

b UNIVERSITÄT BERN

esa enveo GAMMA REMOTE SENSING SYKE

norut NORTHERN RESEARCH INSTITUTE TROMSØ

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

NR Norsk Regnesentral

Environment Canada Environnement Canada

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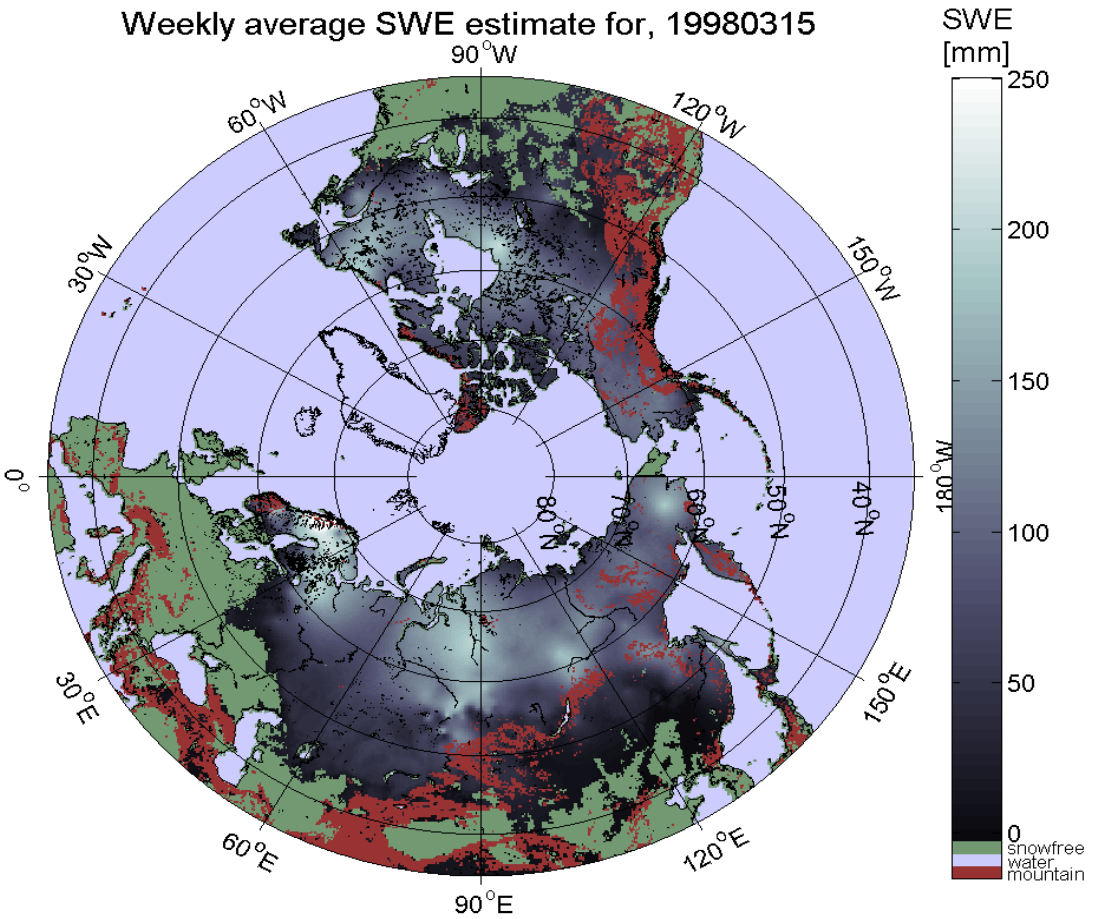
35 year-long CDR time-series on snow conditions of Northern Hemisphere

- First time reliable daily spatial information on SWE (snow cover):
  - Snow Water Equivalent (SWE)
  - Snow Extent and melt (+grain size)
  - 25 km resolution (EASE-grid)
  - Time-series for 1979-2014
- Passive microwave radiometer data combined with ground-based synoptic snow observations
  - Variational data-assimilation
- Available at open data archive (www.globsnow.info)
- Demonstration of NRT processing since October 2010



Takala, M., Luojus, K., Pulliainen, J., Derksen, C., Lemmetyinen, J., Kärnä, J.-P, Koskinen, J., Bojkov, B., "Estimating northern hemisphere snow water equivalent for climate research through assimilation of spaceborne radiometer data and ground-based measurements", Remote Sensing of Environment, Vol. 115, Issue 12, 15 December 2011, doi: 10.1016/j.rse.2011.08.014

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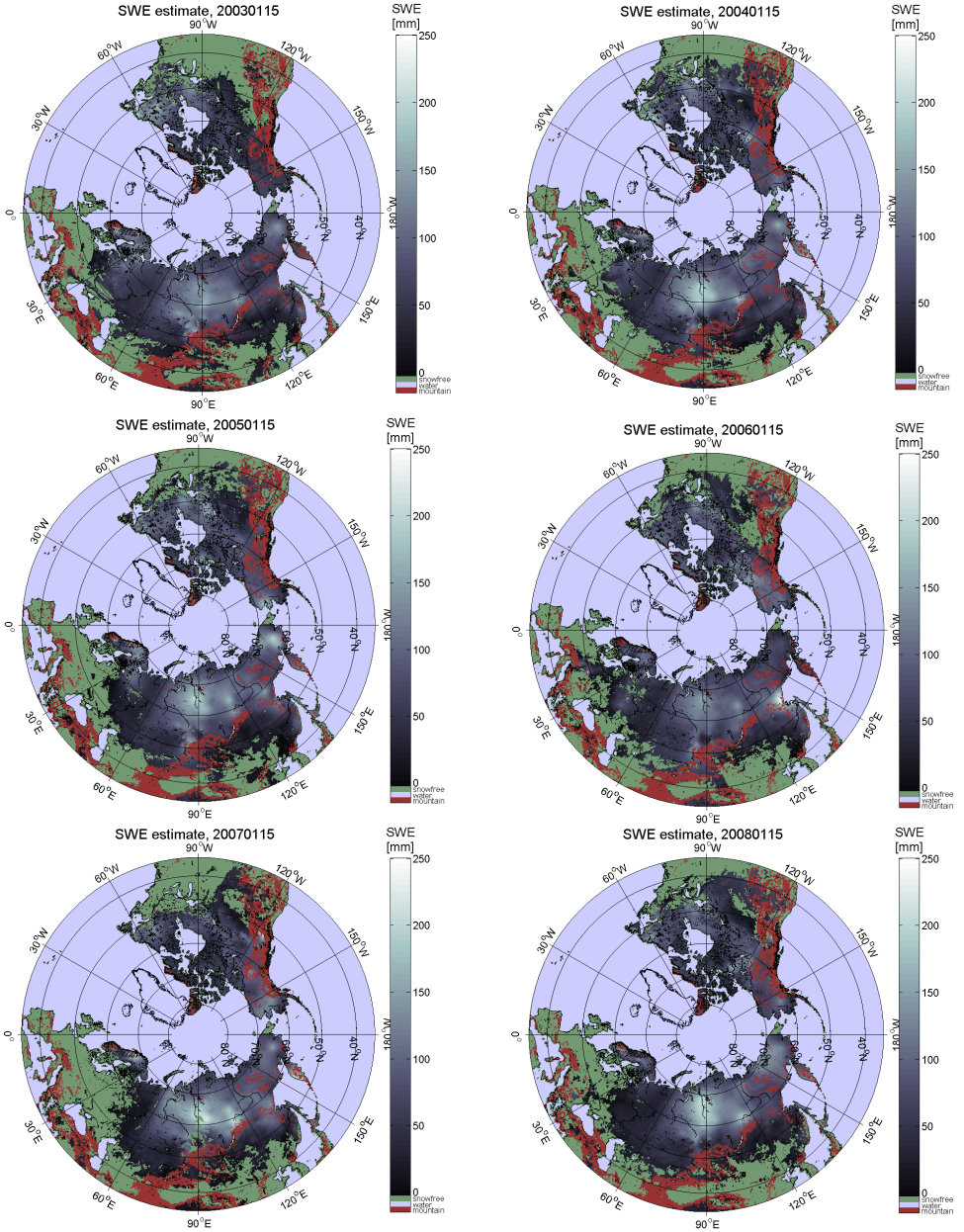
GlobSnow SWE time series (FCDR)

- Northern Hemisphere
  - 1979 to 1987 (SMMR)
  - 1988 to 2013 (SSM/I, SSMIS)
  - *FPS v1.0 2003 to 2011 (AMSR-E)*
- Daily, weekly, monthly products
- Includes error estimates (statistical std of the SWE estimate in mm)
- Data format HDF4 & NetCDF CF
- EASE-Grid projection (~25km resolution)
- snow grain data available as well
- Glaciers, mountains & Ice Sheets masked out

- Versions: 1.0; 1.3 and 2.0 (current)



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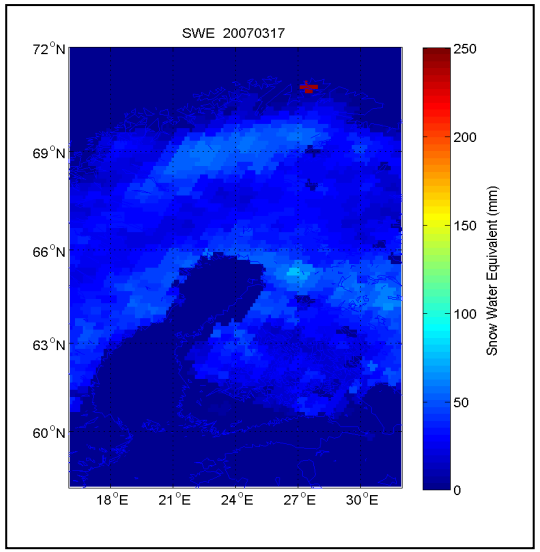
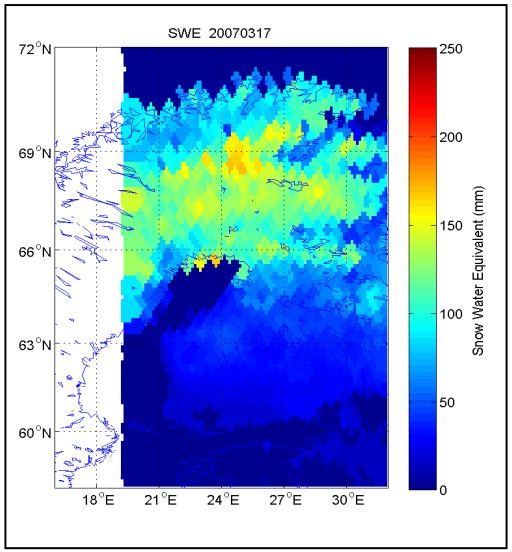
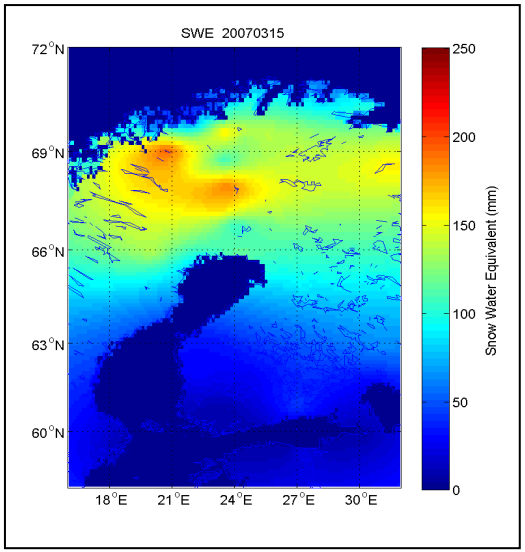
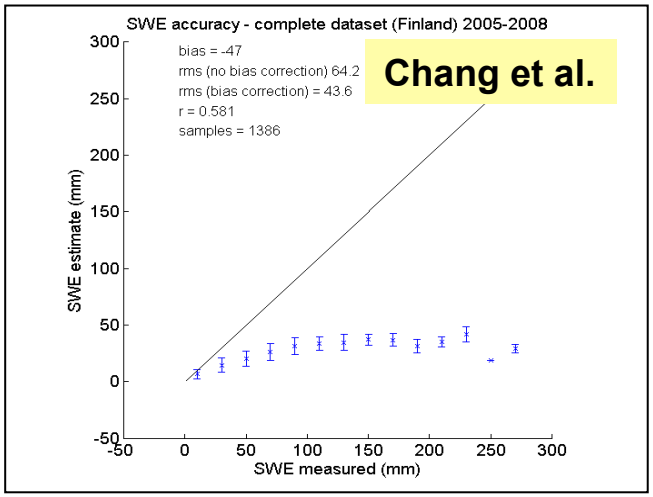
SWE Retrieval 'Saturation' (PMW signal)

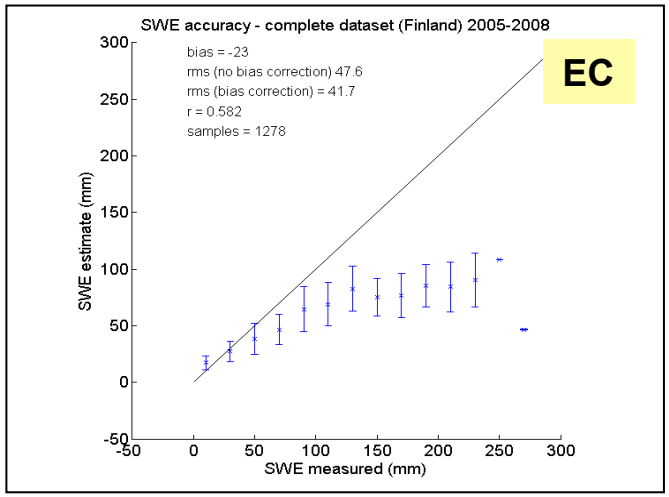
"what if we would not apply the synop data?"

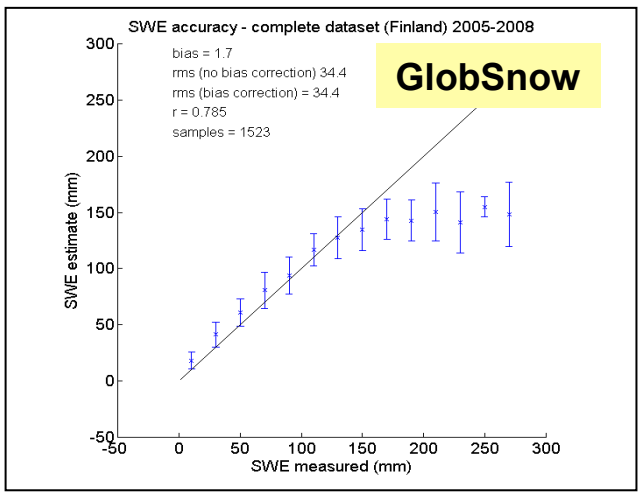












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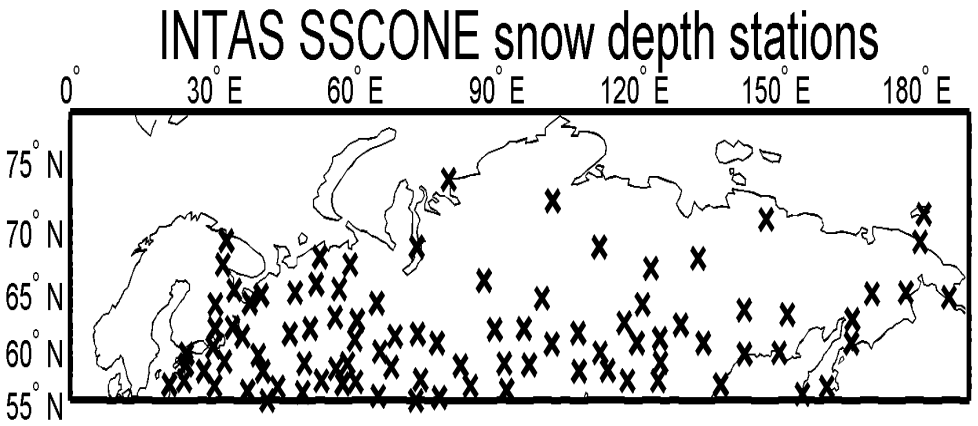
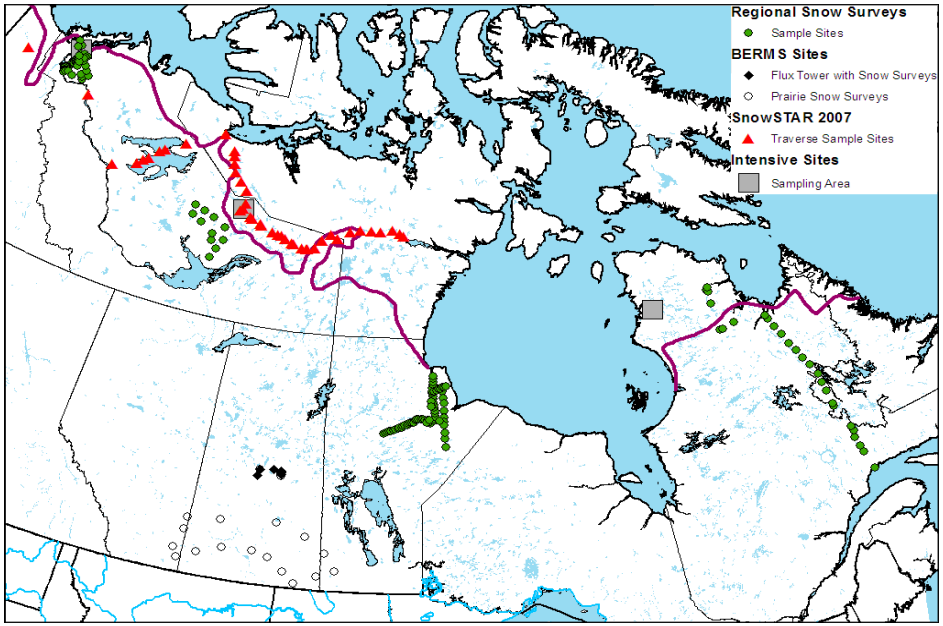
Distributed validation data, e.g. Northern Eurasia & Canada

Snow Survey data (from the former USSR and Russia)

- There are 517 snow path stations with data for (1979 – 2009)
- Manual ground-based measurements on snow depth/SWE
- 1 - 2km snow transects, measurements every 100m - 200m

Land Cover	Reference Dataset	Year	n	Mean SWE (mm)
Tundra	Intensive Sites; SnowSTAR 2007	2006-2008	28	120
Northern Boreal	EC Snow Surveys	2006-2007	105	135
		SWE <150 mm	73	134
Southern Boreal	EC Snow Surveys	2005-2007	57	75
Southern Boreal	BERMS Towers	2005-2008	468	70
Prairie	EC Snow Surveys	2005-2007	41	44





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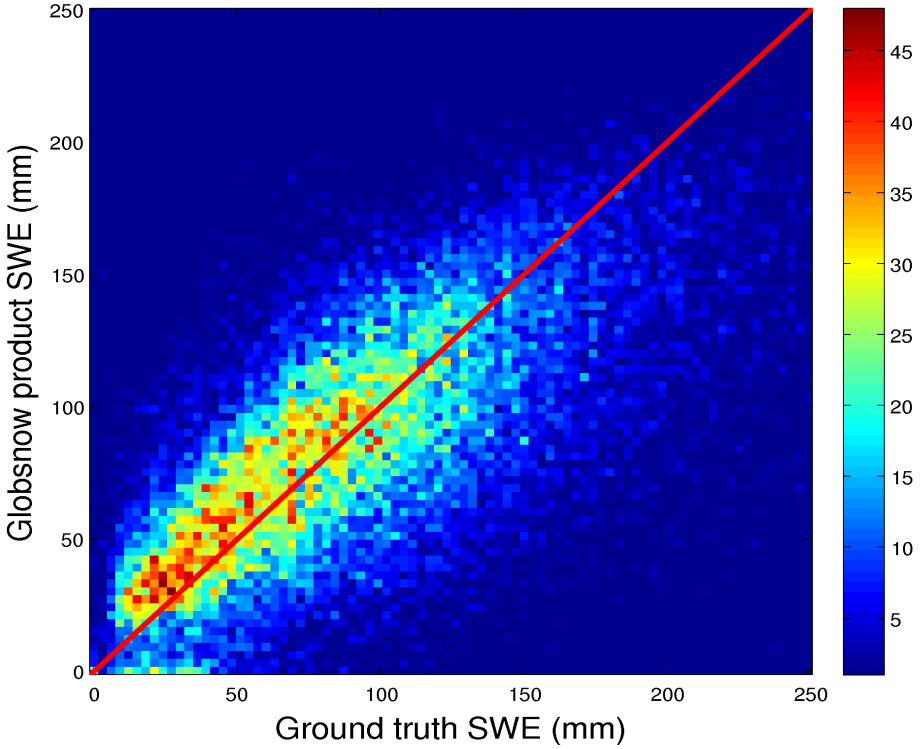
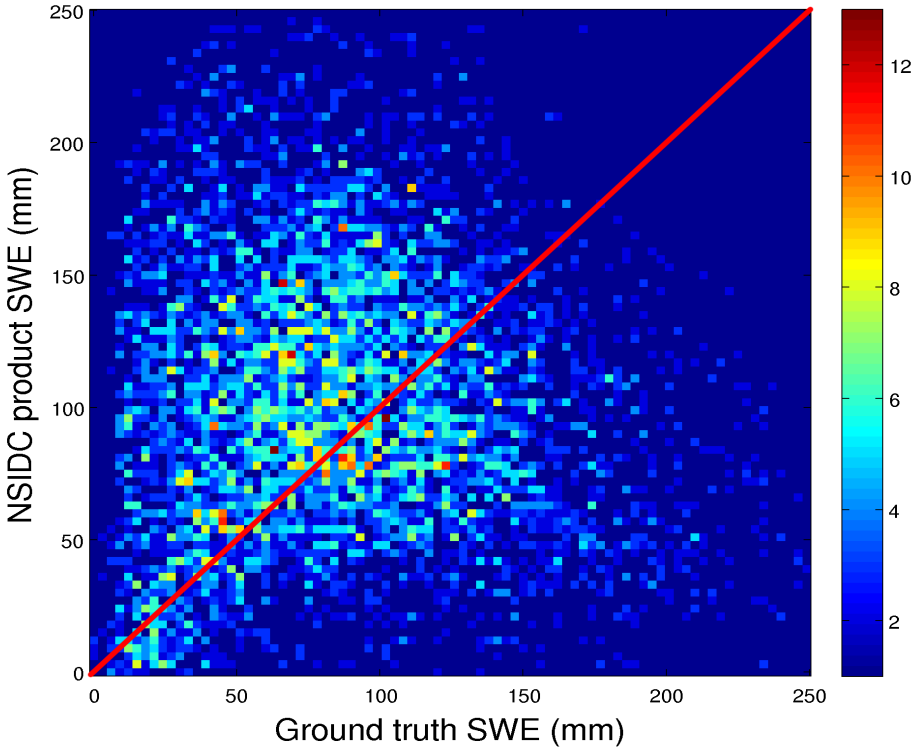
SWE retrieval (data assimilation vs. channel diff.)

- Density scatterplot (assimilated vs. satellite only SWE)
- Russian INTAS SCCONE **SWE transect data** as reference





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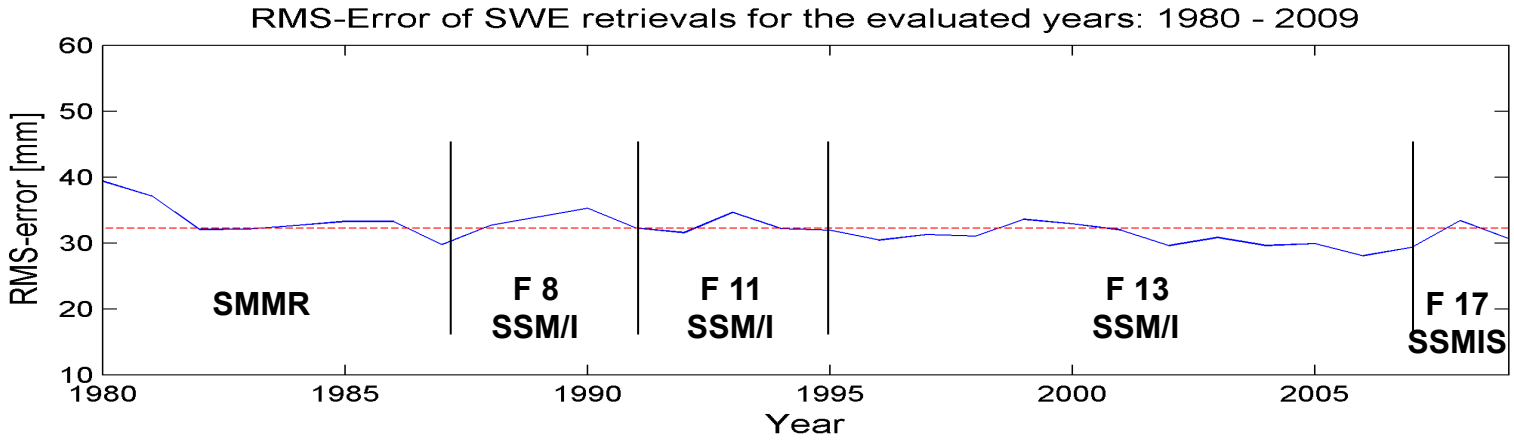
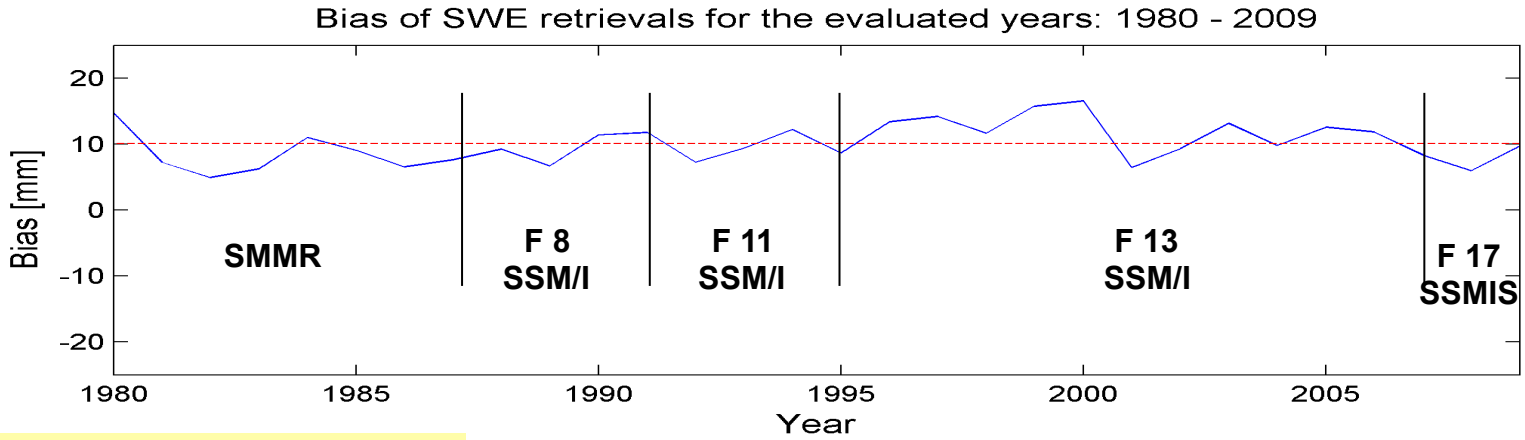
Long term consistency of SWE v2.0 FPS

- RMS error and retrieval bias calculated independently for each year 1980-2009
- Reference data: snow transects from Russia (INTAS-SCCONE)





SWE<150 mm; 146.000 samples

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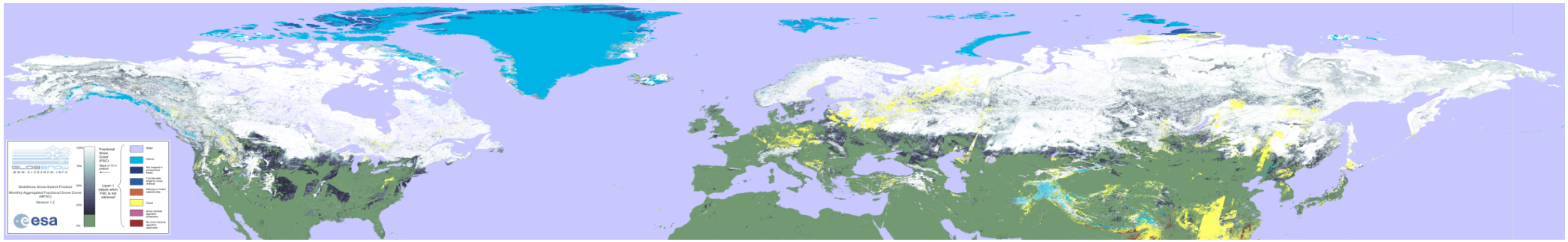
GlobSnow Snow Extent (SE) dataset

- 17 years SE data record has been produced using optical imagery from ESA ATSR-2 (1995-) and AATSR (2002-) on a hemispherical scale. NPP VIIRS from 2012-
- SYKE's *SCAmod* method for fractional snow cover mapping implemented for Northern hemisphere
- Cloud detection algorithm developed by SYKE (+ contributed by ENVEO, FMI & NR)



- Methodology developed especially for forested regions – basically a tough challenge for optical SE retrieval
- Uncertainty estimate provided for each grid cell, data available as NetCDF CF
- Operational data production at the Finnish Meteorological Institute (FMI)

Metsämäki, S., Mattila, O.-P., Pulliainen, J., Niemi, K., Luojus, K., Böttcher, K. "An optical reflectance model-based method for fractional snow cover mapping applicable to continental scale", Remote Sensing of Environment, Vol. 123, August 2012, pp. 508-521, doi: 10.1016/j.rse.2012.04.010.

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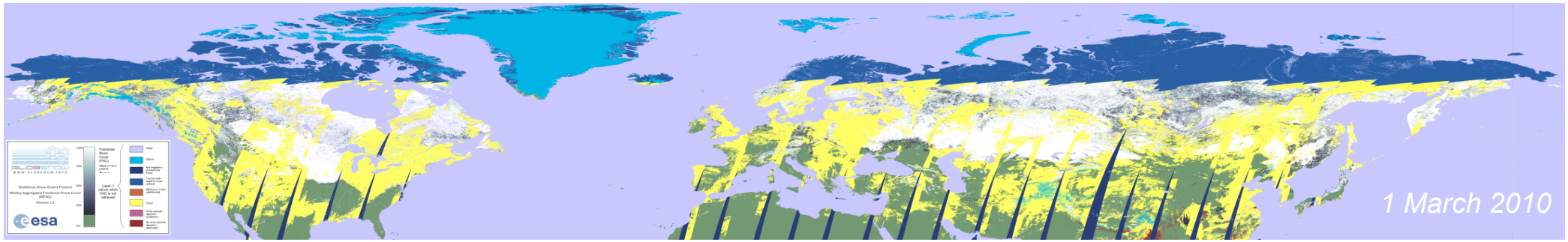
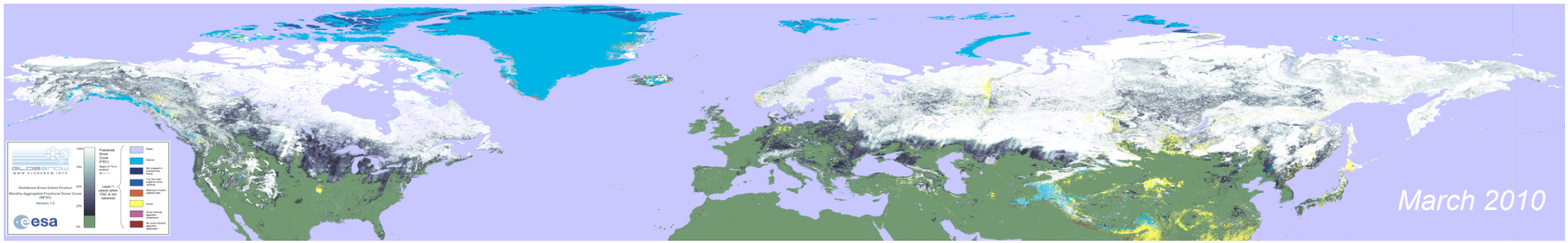
Daily, weekly and monthly products

Optical data ~ 1km spatial resolution





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SCAmod retrieval algorithm

- Based on reflectance model where forest canopy effect into the observed reflectance is compensated through pre-determined canopy *transmissivity*
- Designed to provide FSC in forested areas, and overall well applicable globally over any terrain
- A single band approach - Applicable to optical wavelengths and to a variety of sensors

Volume scattering *Surface scattering*

$$\rho_{\lambda,obs}(FSC) = (1-t_\lambda^2)*\rho_{\lambda,forest} + t_\lambda^2 * \left[FSC*\rho_{\lambda,snow} + (1-FSC)*\rho_{\lambda,ground}\right]$$

$$FSC = \frac{\frac{1}{t_\lambda^{\,2}} * \rho_{\lambda,obs}(FSC) + (1-\frac{1}{t_\lambda^{\,2}}) * \rho_{\lambda,forest} - \rho_{\lambda,ground}}{\rho_{\lambda,snow} - \rho_{\lambda,ground}}$$

$\rho_{\lambda,obs}(FSC)$ observed reflectance from unit area
$\rho_{\lambda,snow}$ wet snow reflectance
$\rho_{\lambda,ground}$ snow-free ground reflectance
$\rho_{\lambda,forest}$ forest canopy reflectance
$\hat{t}_\lambda$ forest canopy transmissivity for unit area
FSC fraction of snow covered area

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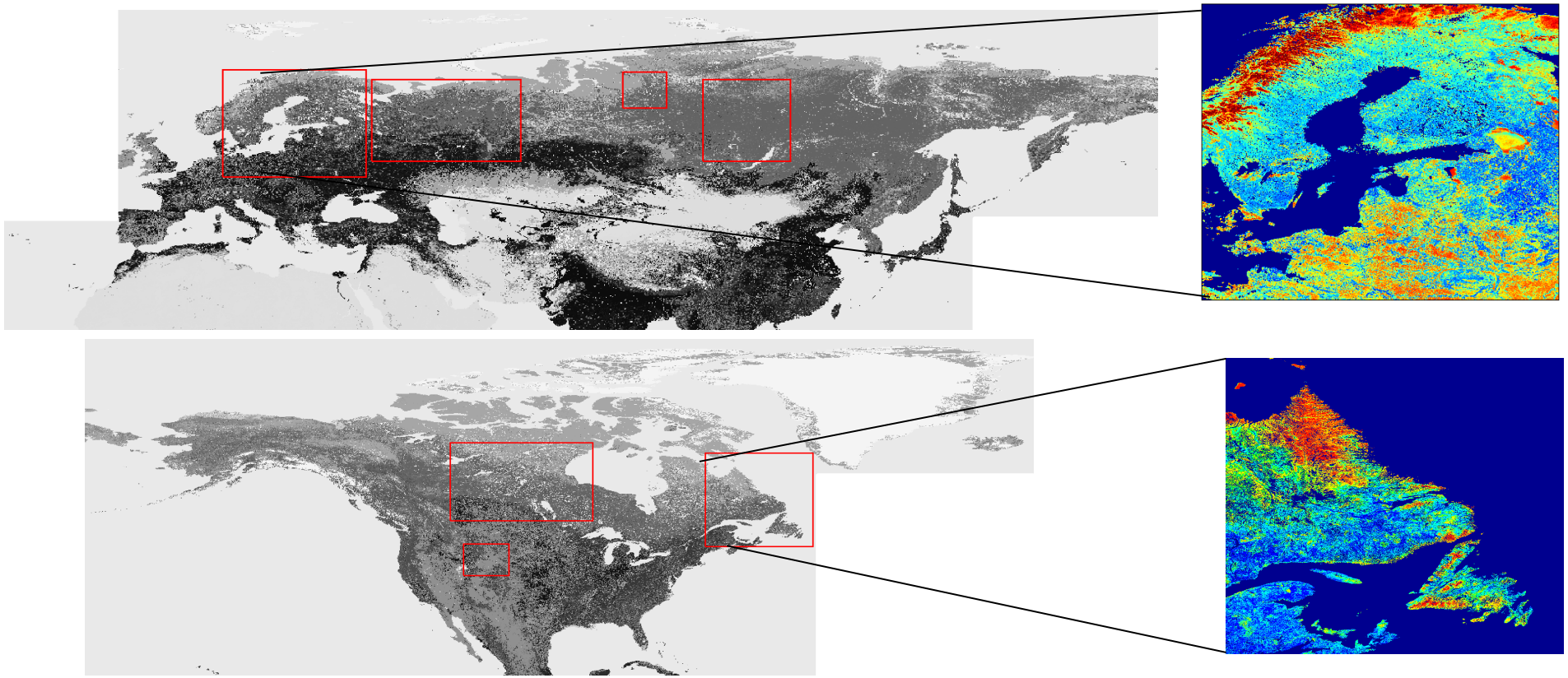
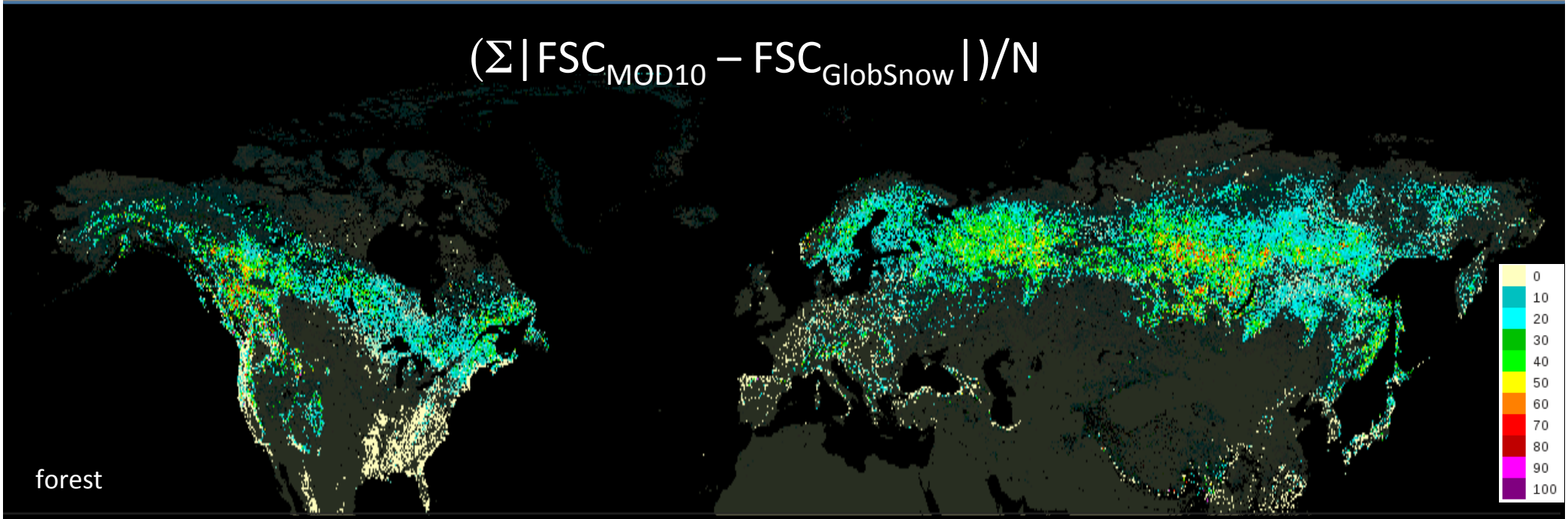
Transmissivity has a key role in FSC-estimation (retrieval accuarcy for forests)

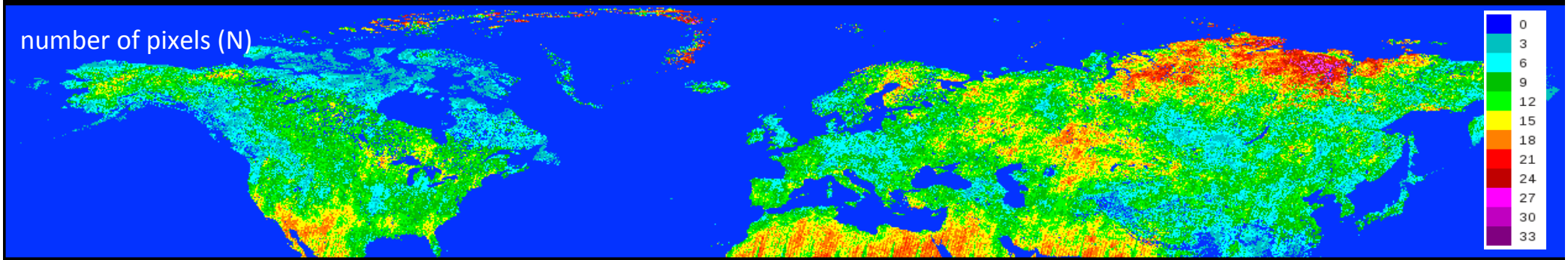
- Transmissivity from MODIS (550nm) reflectance data for several training areas
- Statistical analysis for MODIS-derived transmissivity vs. GlobCover data over the training areas → Transmissivity statistics (Mean and standard deviation) for each GlobCover class



Mean Absolute FSC Difference
MOD10 versus GlobSnow - 1.3.-31.5.2010

$$(\Sigma|FSC_{MOD10} - FSC_{GlobSnow}|)/N$$





Thomas Nagler / ENVEO

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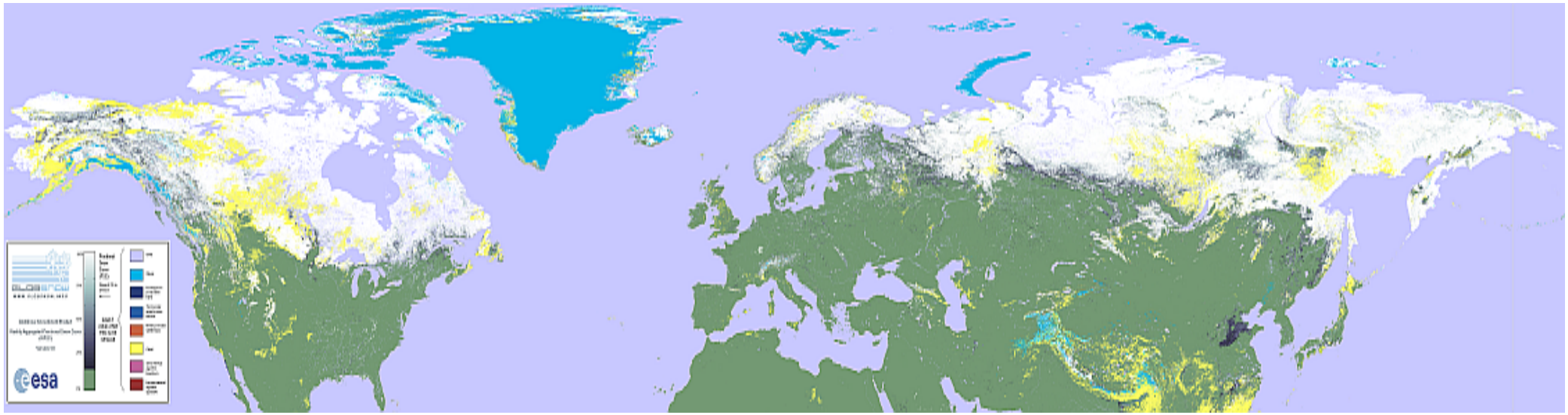
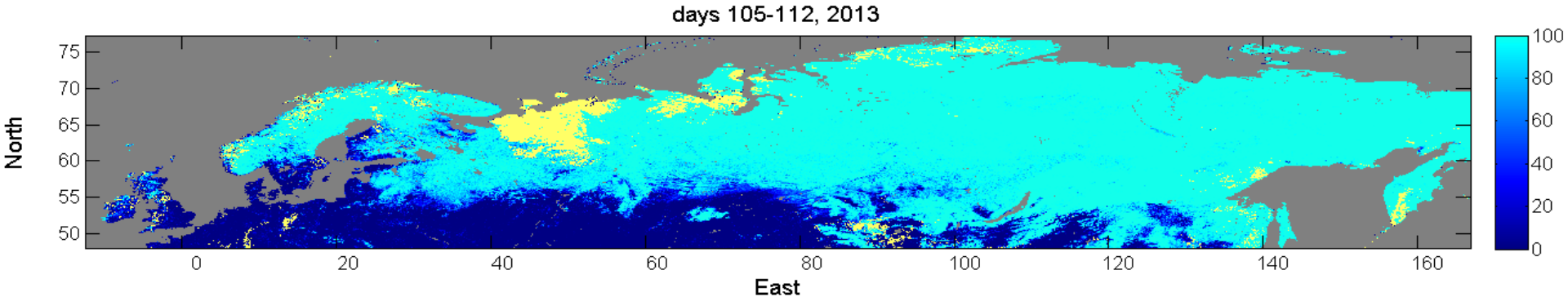
GlobSnow-2, Suomi NPP VIIRS SE product

~1km spatial resolution, daily hemispherical coverage
NRT production since early 2013

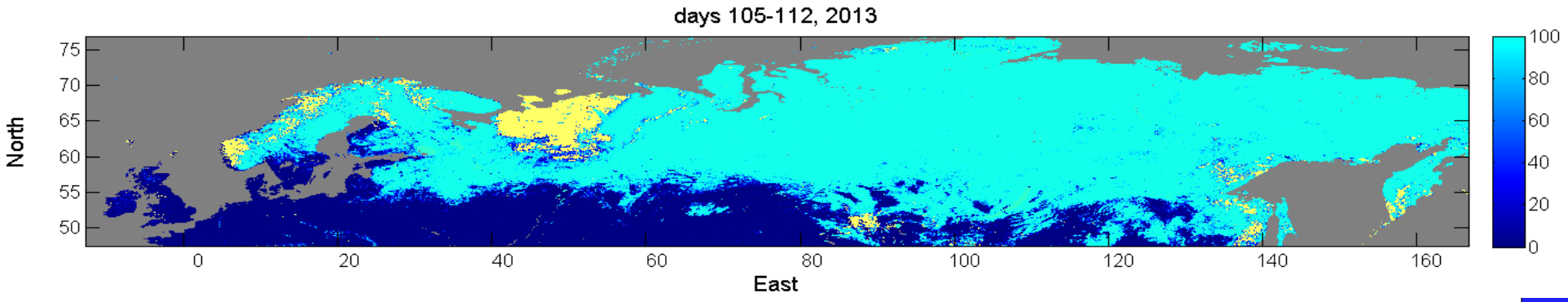


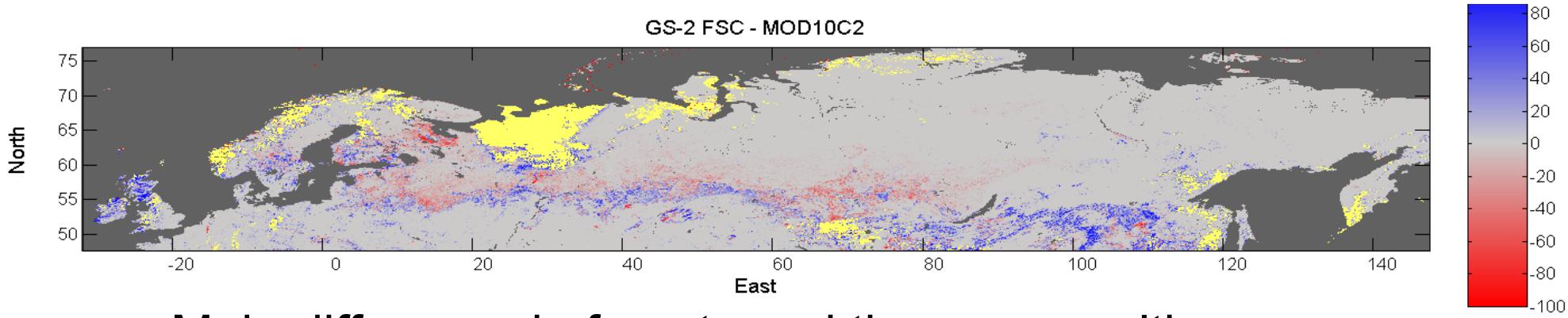
GlobSnow VIIRS SE vs. NASA MOD10C2

GS-2 VIIRS FSC



NASA MOD10C2





Main difference in forests and the snow melting zone

Utilization of GlobSnow SWE datasets

- SWE time-series and NRT processing applied in a WMO Global Cryosphere Watch ”SWE-tracker”
- SWE time-series vs. CMIP5 simulations

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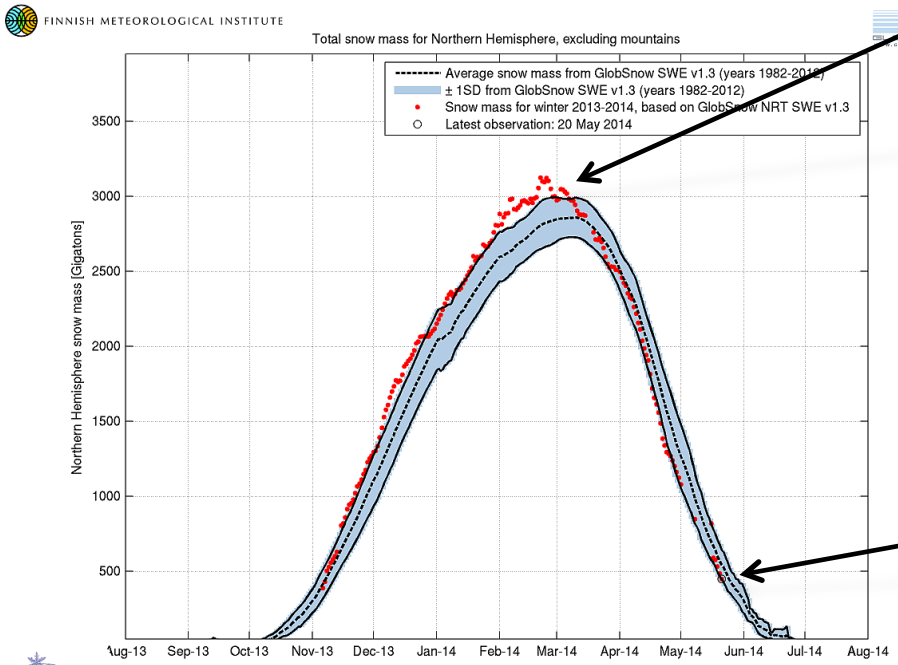
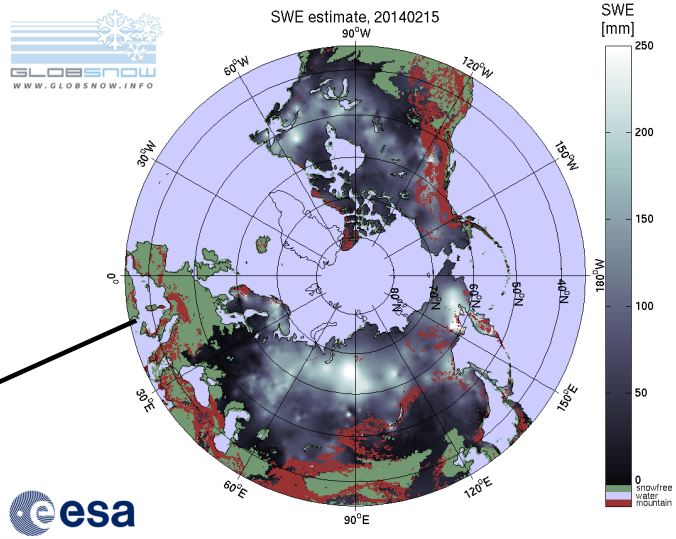
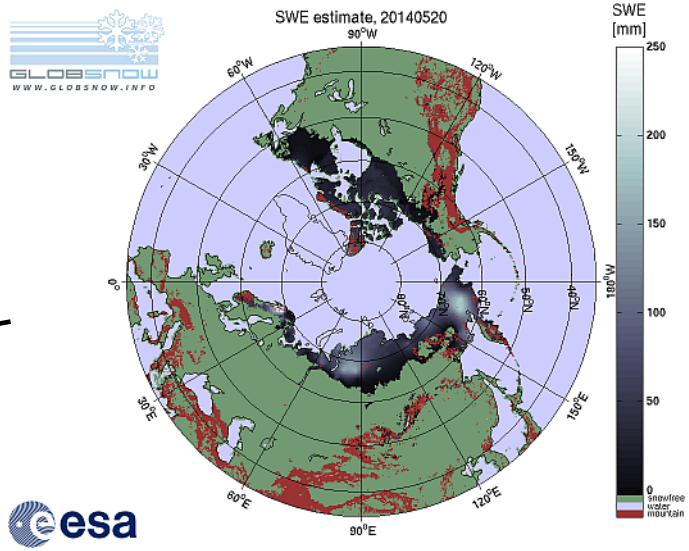
Tracking NH snow cover evolution in NRT

WMO GCW NH Snow tracker (based on FMI GlobSnow SWE processor)

•Tracking of hemispherical scale SWE/ snow mass (anomalies) in NRT utilizing the GlobSnow long term time-series as a ”reference”







GCW Global Cryosphere Watch

20 May 2014

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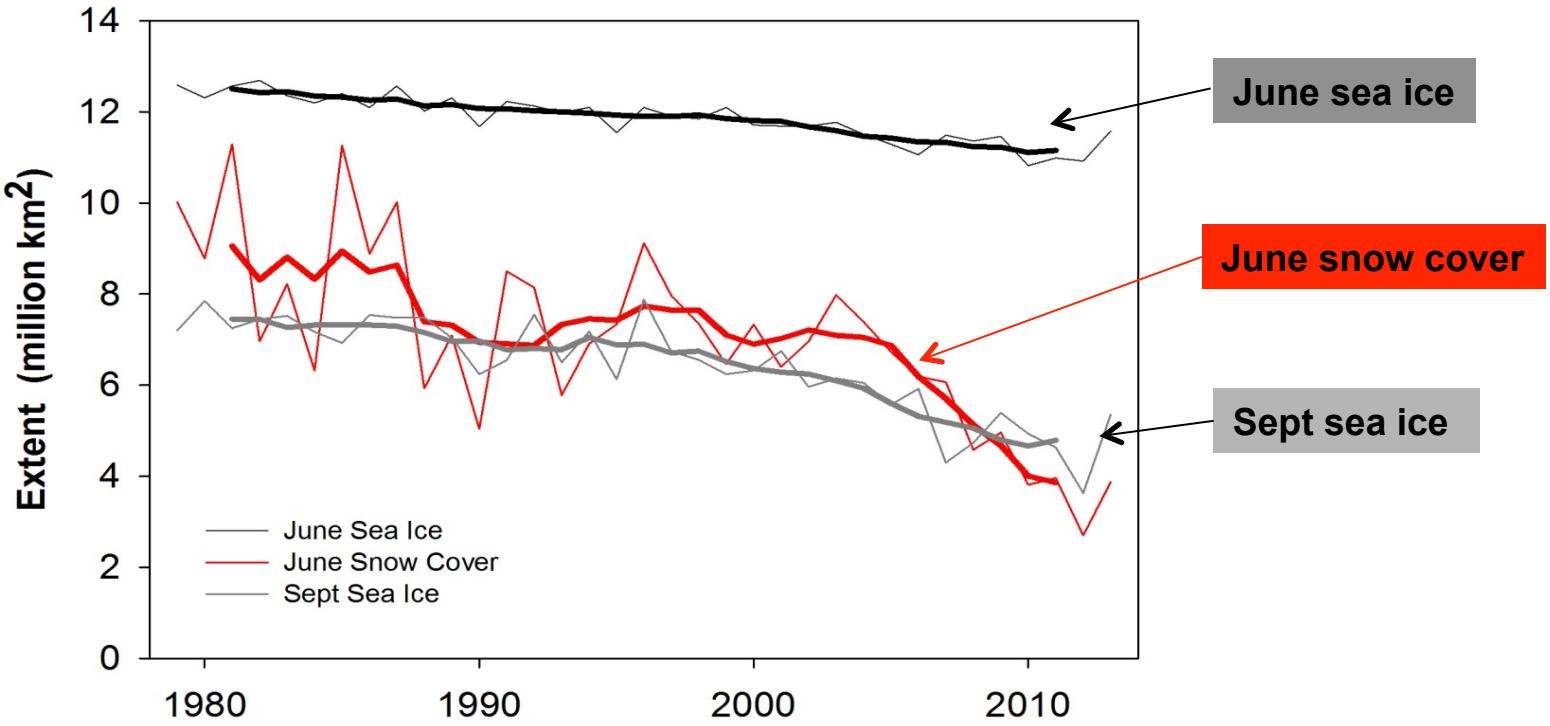
Motivation: Changes in Snow Extent vs. Sea

Northern hemisphere June snow cover and Arctic sea ice extent, 1979-2013



- For 1979–2013, June SE decreasing at rate of -19.9% per decade (relative to 1981-2010 mean)
- September sea ice extent is decreasing at rate of -13.7% per decade. ***Derksen, C Brown, R (10.10.2012) GRL***

- **Estimated decay in radiative forcing (cryospheric cooling) receive nearly equal contributions from land snow cover and sea ice**
  (Flanner et al. 2011 – *Nature Geoscience Letters, March 2011*)

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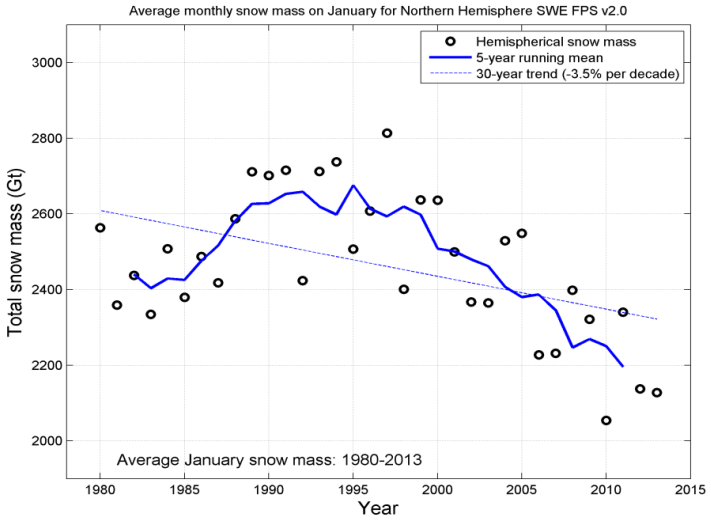
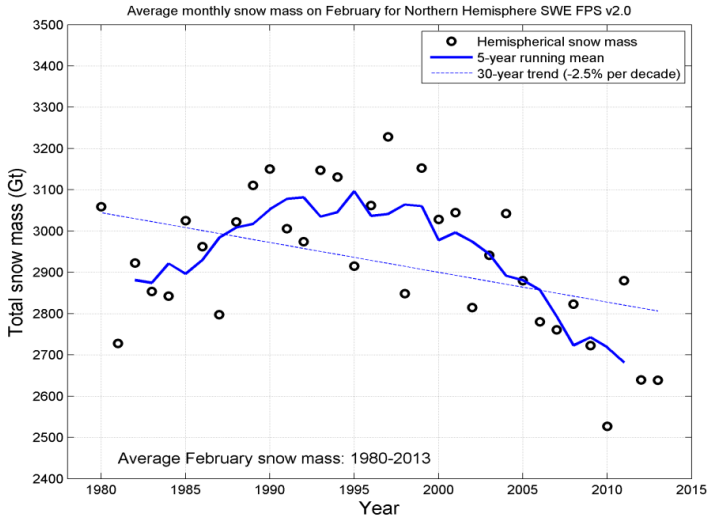
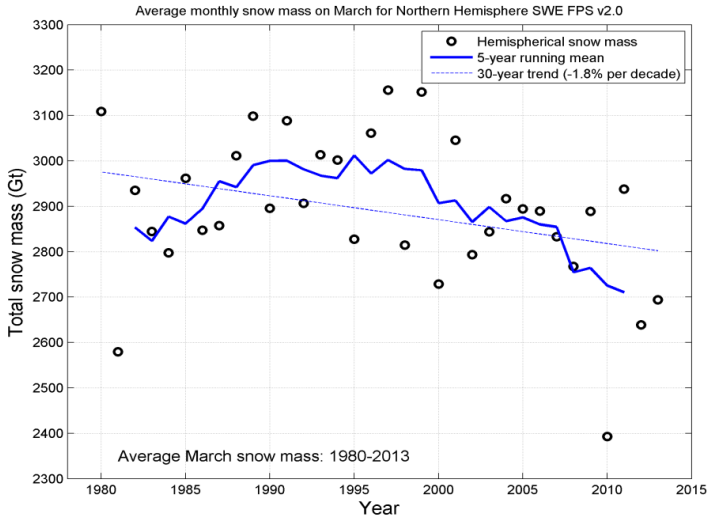
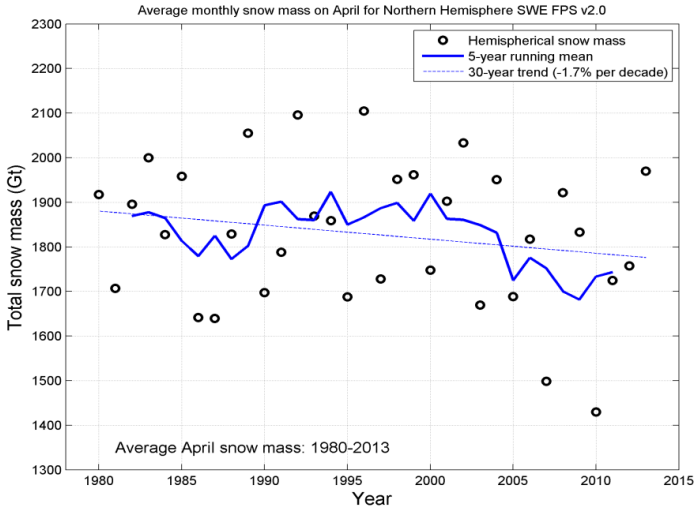
NH trends of snow mass SWE FPS v2.0 1980-2013 (January – April)





Average decrease of -7% in Snow Mass for 30-years





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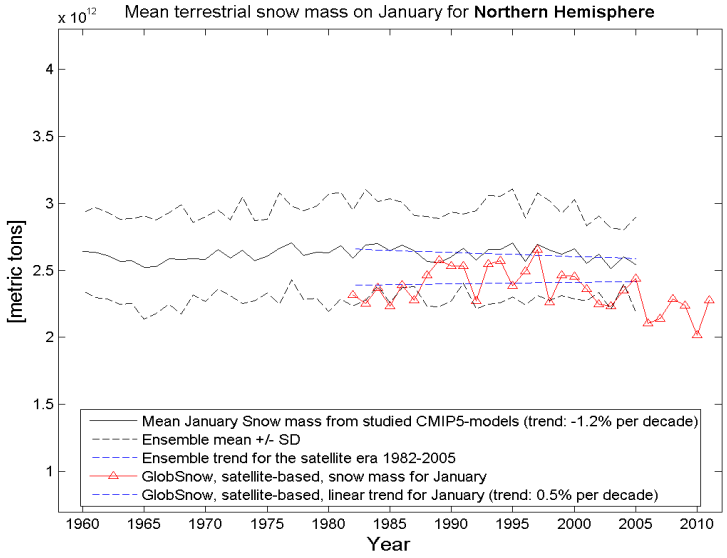
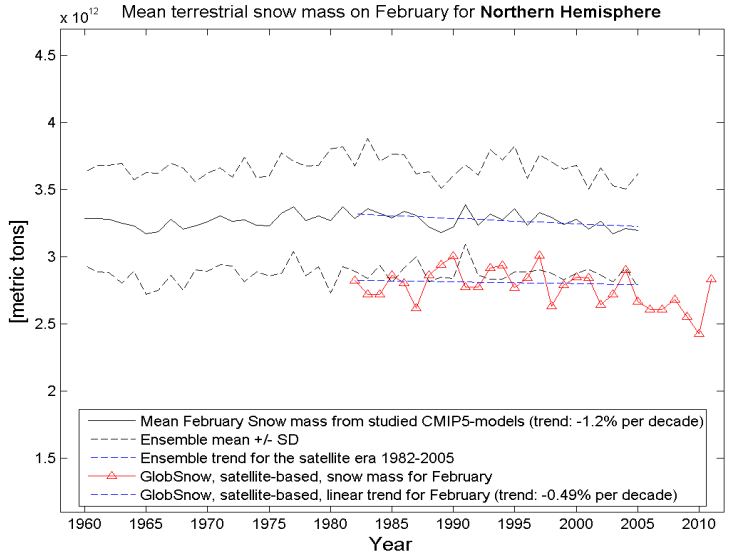
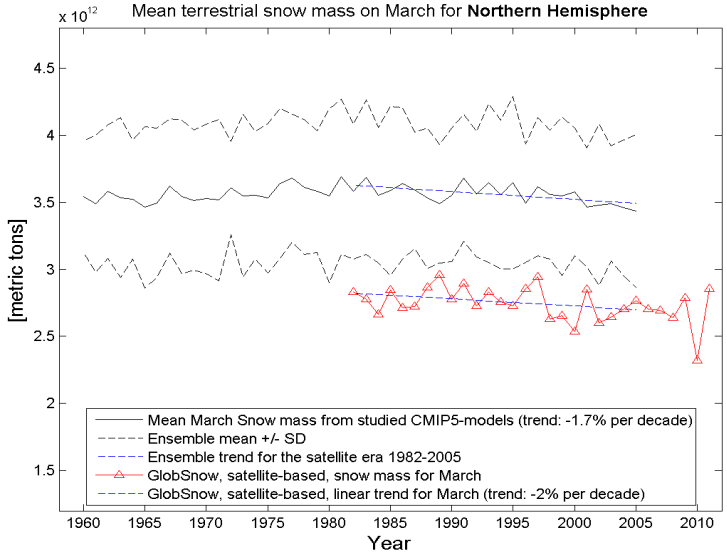
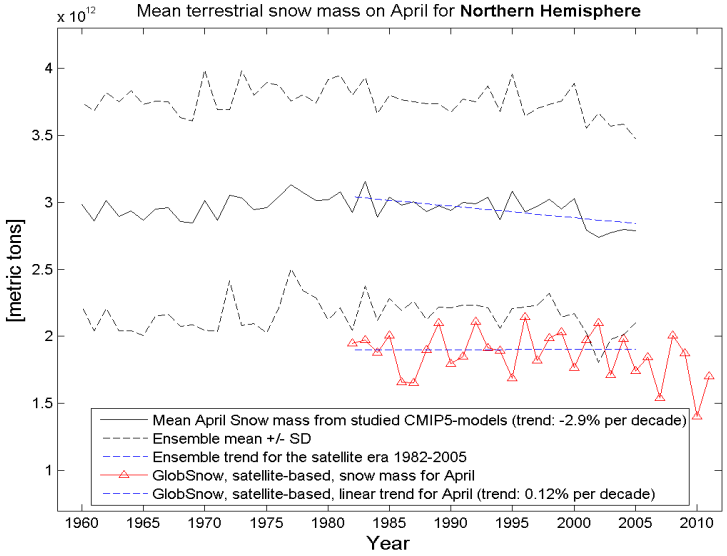
CMIP5 vs. GlobSnow SWE (Jan - April)









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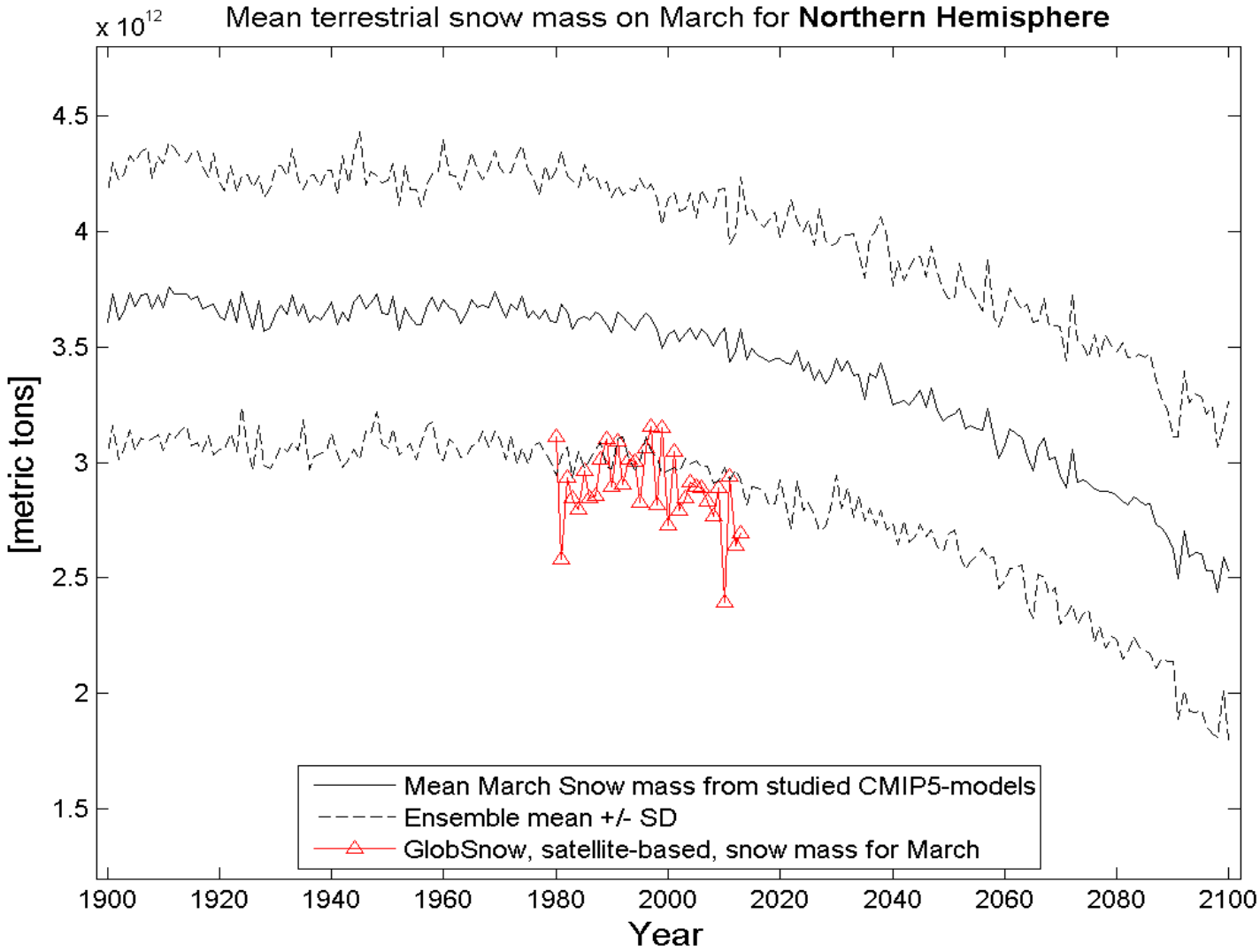
GlobSnow v2.0 SWE vs. Ensemble historical & RCP8.5 ”forecast”

March, Preliminary: 16 models



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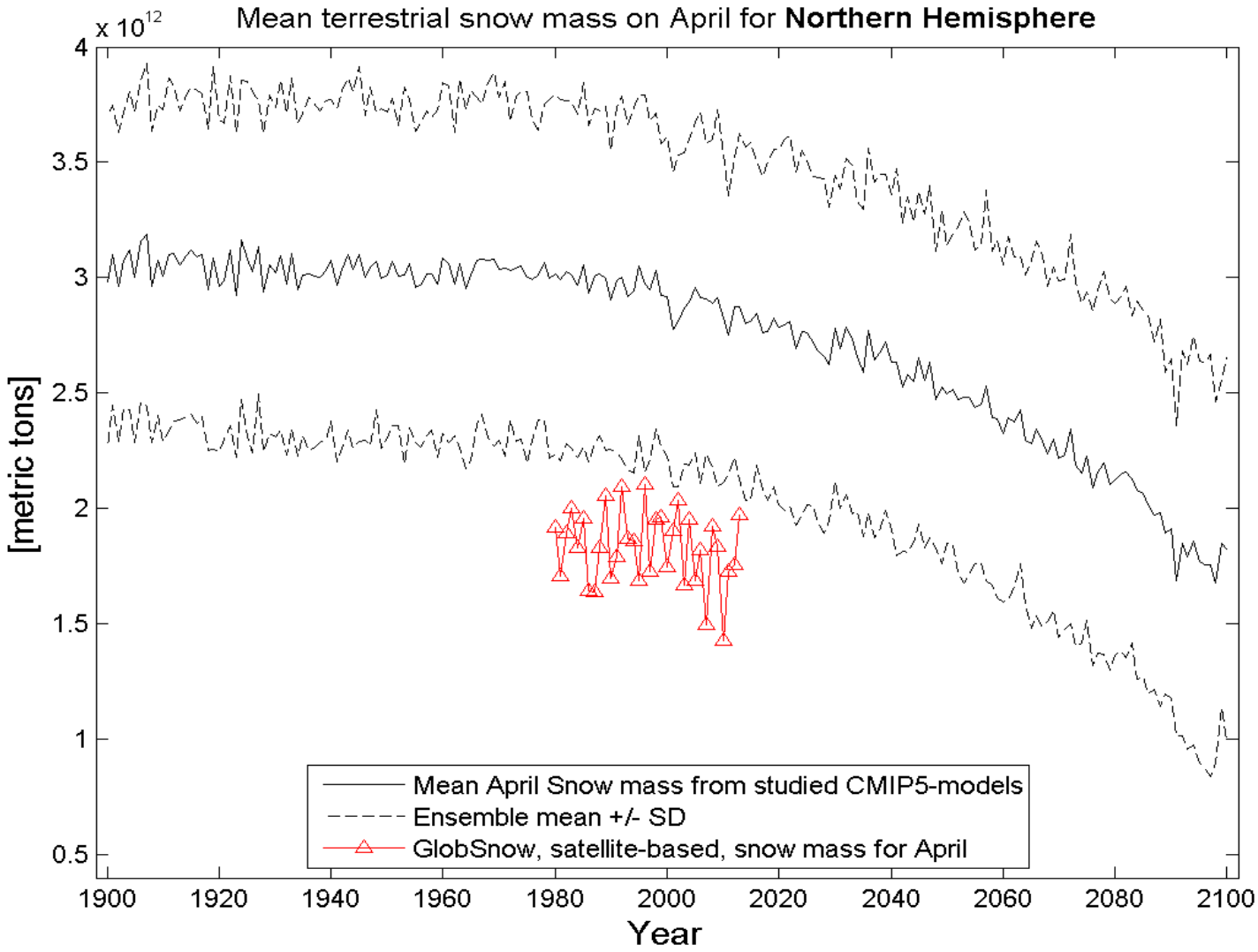
GlobSnow v2.0 SWE vs. Ensemble historical & RCP8.5 ”forecast”

April, *Preliminary: 16 models*



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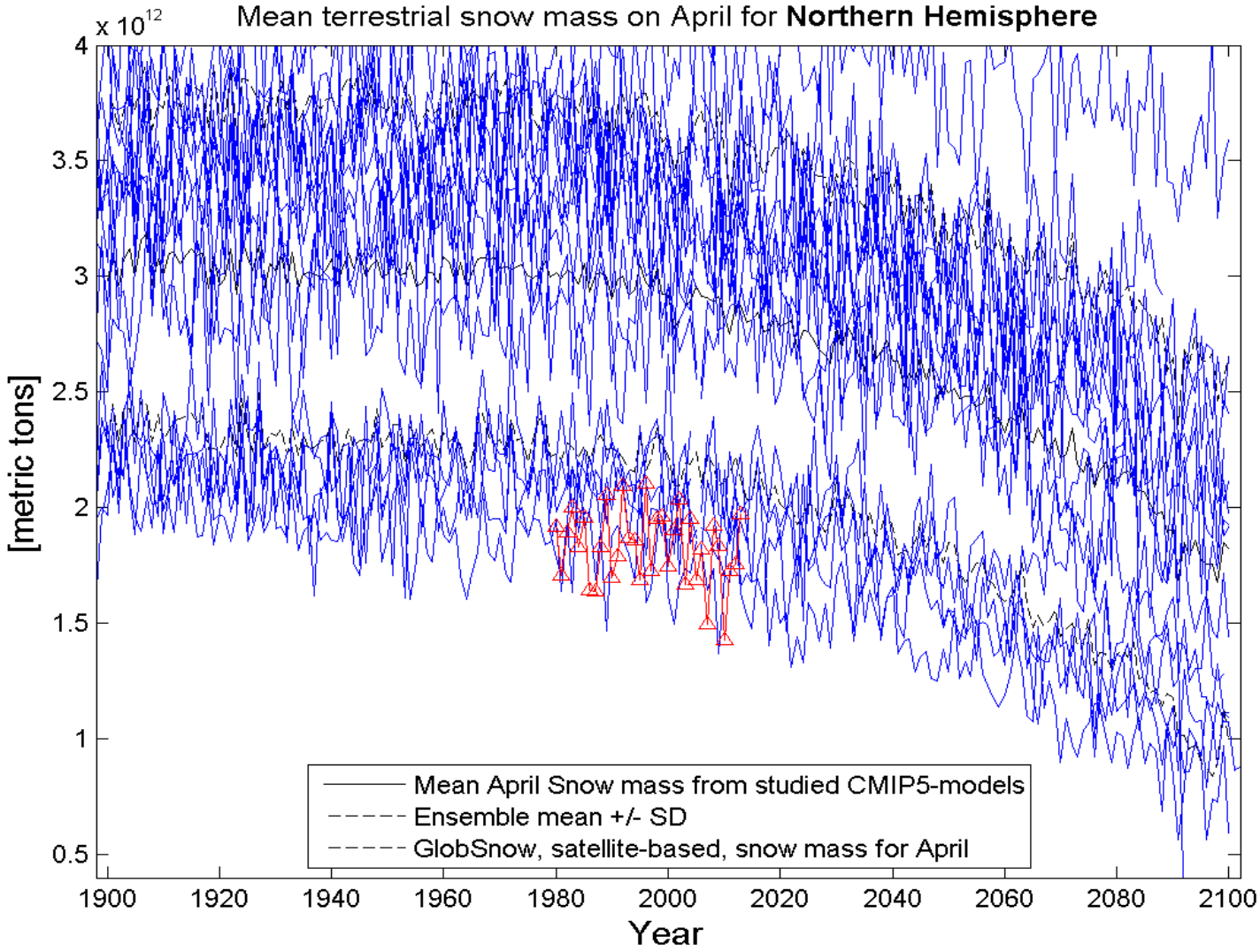

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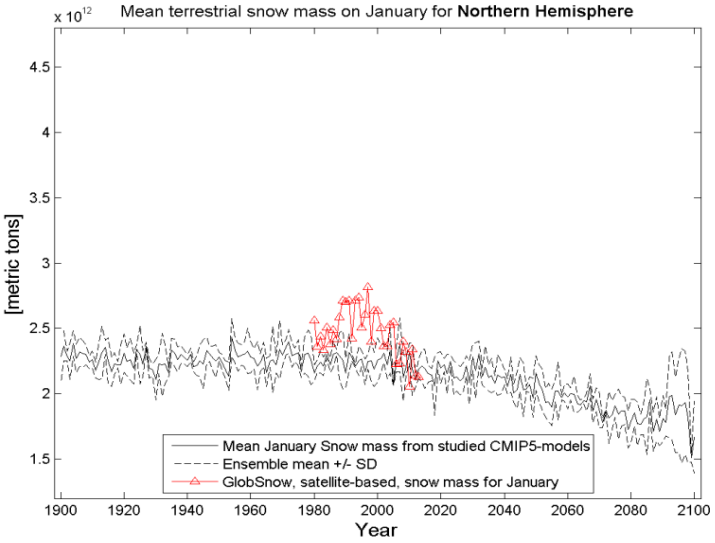
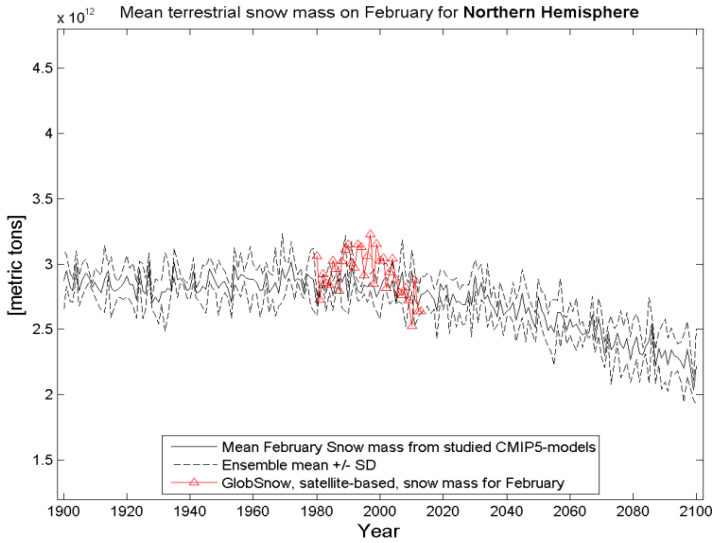
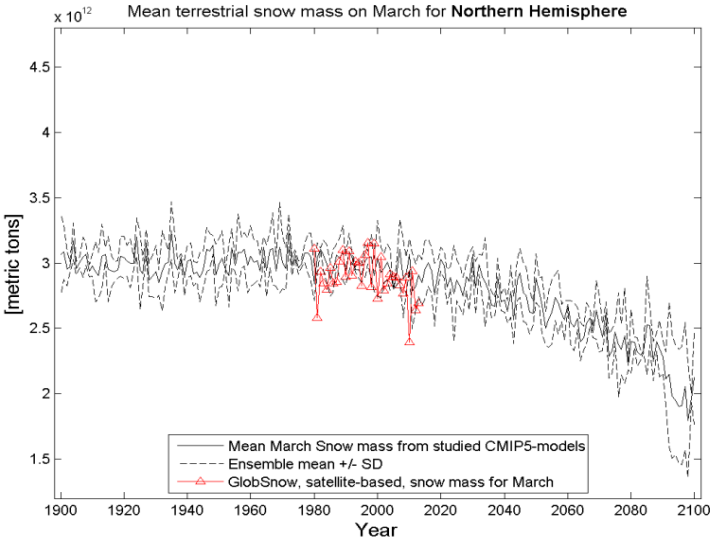
GlobSnow v2.0 SWE vs. *3 UKMO Hadley Center HADGEM2 models*

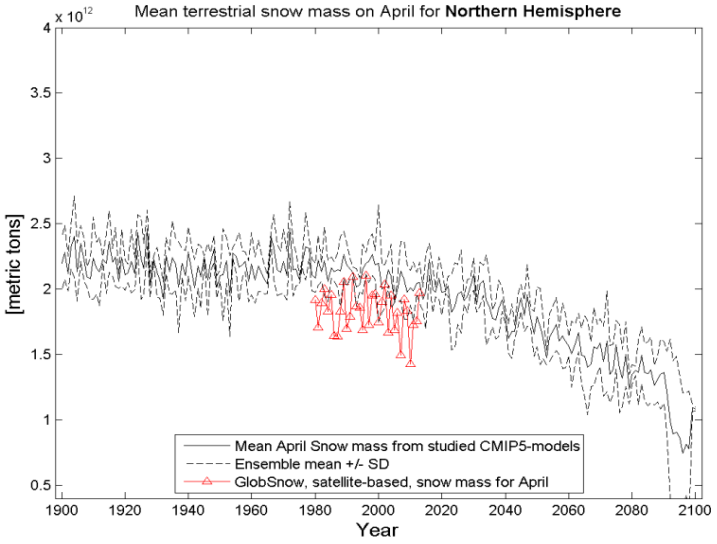
Key observations:

- Most models overestimate the springtime NH SWE
- MPI is the only to clearly under-estimate
- UK HadGEM2 seems to best match the SWE observations









Future ambitions

- Combination of SWE and SE time-series (Snow ECV/CDR)
- High resolution SWE product

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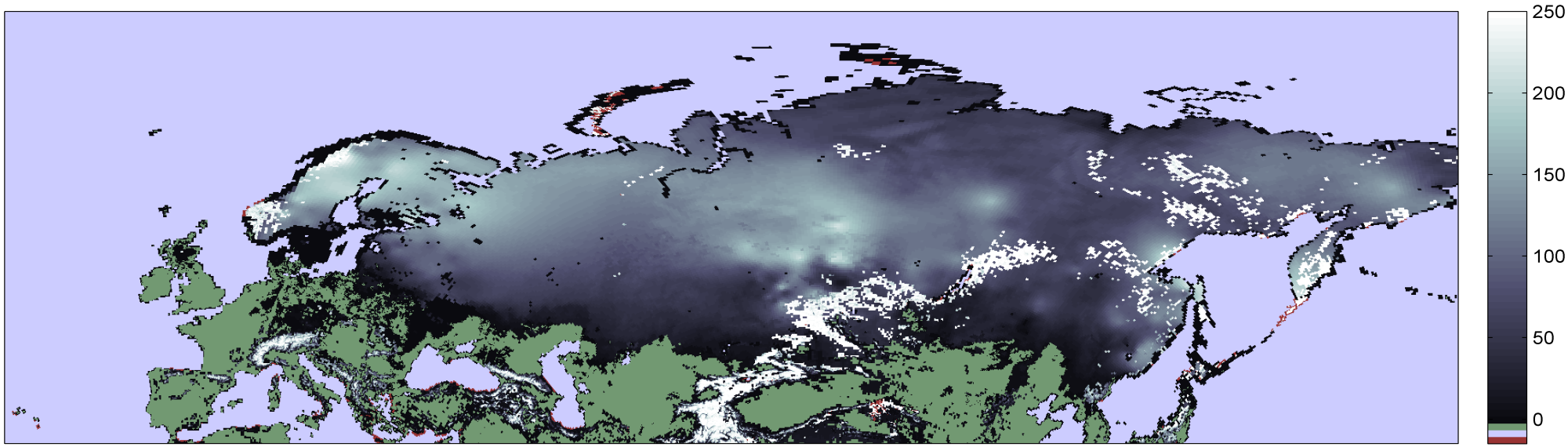
Ongoing work: Combination of SE & SWE products for the generation of concise snow cover information

- NRT north-hemisphere daily snow monitoring product combining GlobSnow SWE and SE products (based on SSMI-S and VIIRS+Sentinel-3)
- Utilization of NOAA IMS as an SE source for NRT production (esp. winter)



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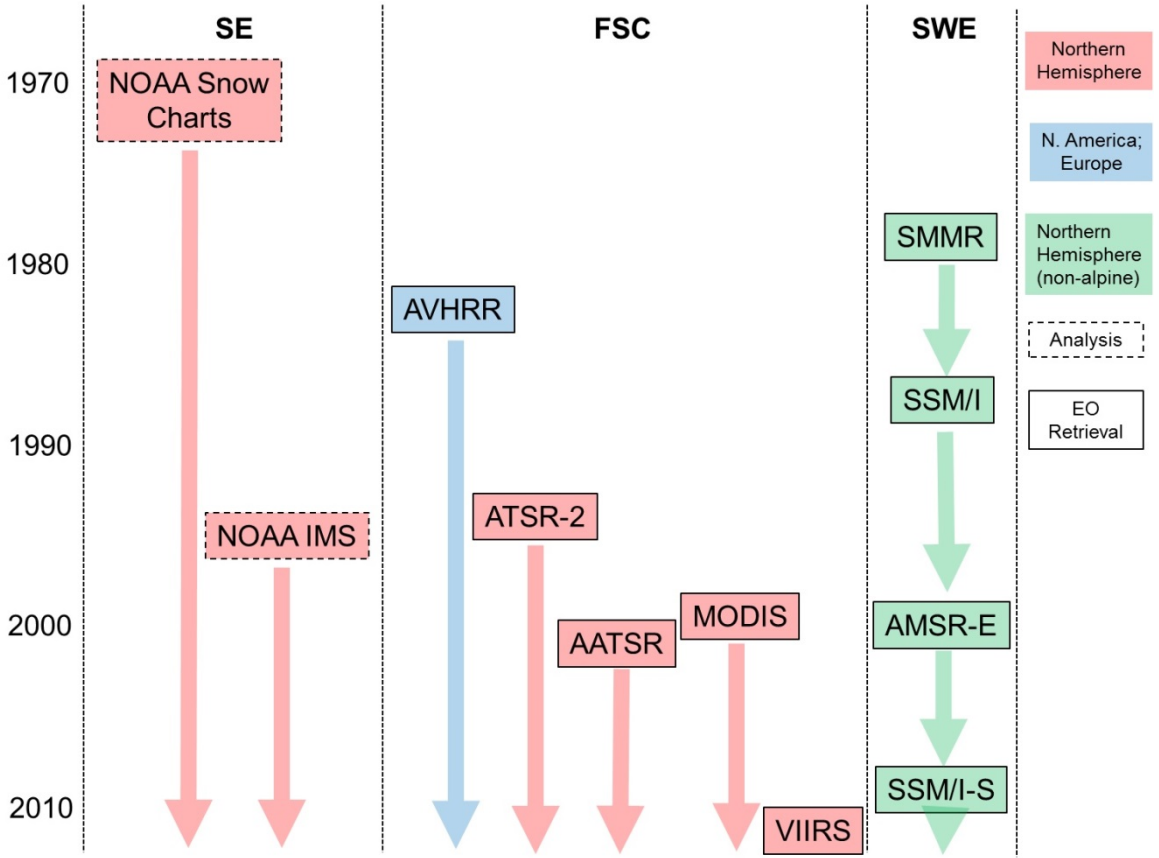
Future ambition regarding a snow “ECV” for Northern Hemisphere

- Future ambition:
  - PMW SWE augmented with snow line from optical data
  - PMW SWE using variations in retrieval

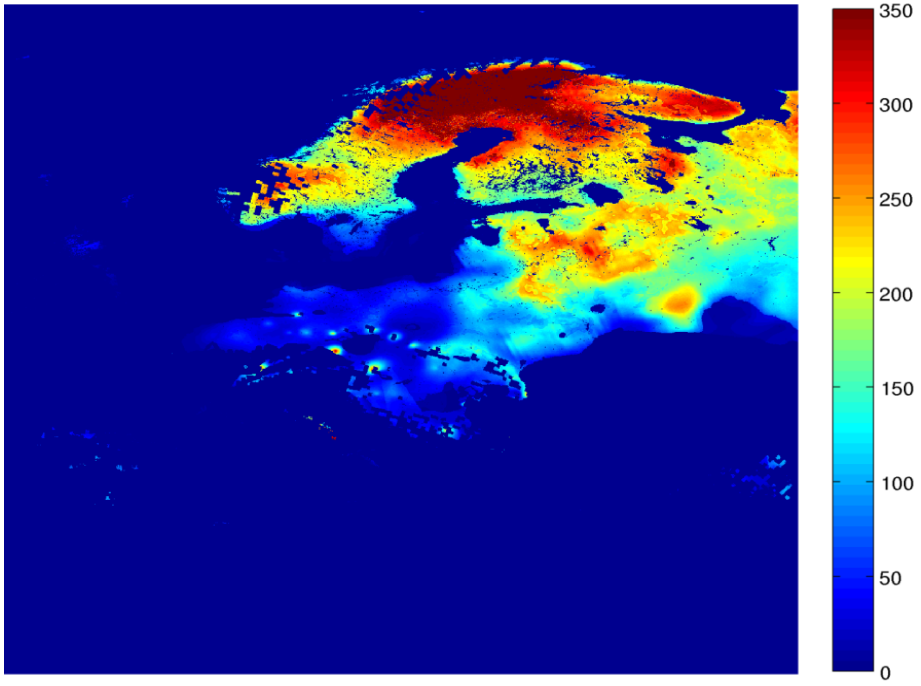


High resolution (5km) Pan-European SWE product

High resolution SWE (in development stage)

- SWE retrieval based on enhanced GlobSnow approach (development on-going)
- Fractional snow cover information used for:
  - improved snow detection during winter snow accumulation period
  - Improved melt detection during spring
- Utilization of optical (VIIRS-based) data in combination with NOAA IMS (4km) product
- Processing for Pan-European domain

- Test phase: winter 2014-2015
- Initial operations: winter 2015-2016



Example of current development version of high resolution SWE product (SWE for 16 March 2013)

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GlobSnow SWE Summary (State-of-the-art today, globally)
GlobSnow vs. alternative SWE datasets

Temporal extent

- Alternative long term datasets on Global scale: Monthly from 1978, daily from 2002

  GlobSnow: Daily 35 years (… begins from autumn 1979)

Thematic accuracy

- Current alternative algorithms
  - Global scale 40mm – 200mm
  - Regional scale 20mm – 50mm (methods often regionally adjusted)
- GlobSnow algorithm:
  - **RMSE of 43.4 mm for Eurasia (diagnostic dataset; > 161 000 samples)**
  - RMSE of 32.1 mm for Eurasia (for SWE < 150mm; >144 000 samples)

Error estimates (error bars)

- Alternative methods do not provide information on estimation error
- **GlobSnow SWE algorithm: Error estimates for each SWE estimate**

Additionally, GlobSnow provides an ensemble of 3 different products: v1.0; v1.3; v2.0

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Summary of GlobSnow

Production of novel global **snow extent (SE)** and **snow water equivalent (SWE)** climate data records (17 and 35 years of snow cover information)

- Version 2.0 for SWE and SE are available

SWE: the first reliable long term satellite based record on SWE
SE: a new FSC retrieval methodology for northern hemisphere (esp. forests)

The near-real-time GlobSnow processing system online at least for 2014-2015

Products “permanently” available via www.globsnow.info

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