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Current status of satellite data-aided research on snow cover: Some findings from ESA's "Earth Observation and Cryosphere Science Conference" on November 2012

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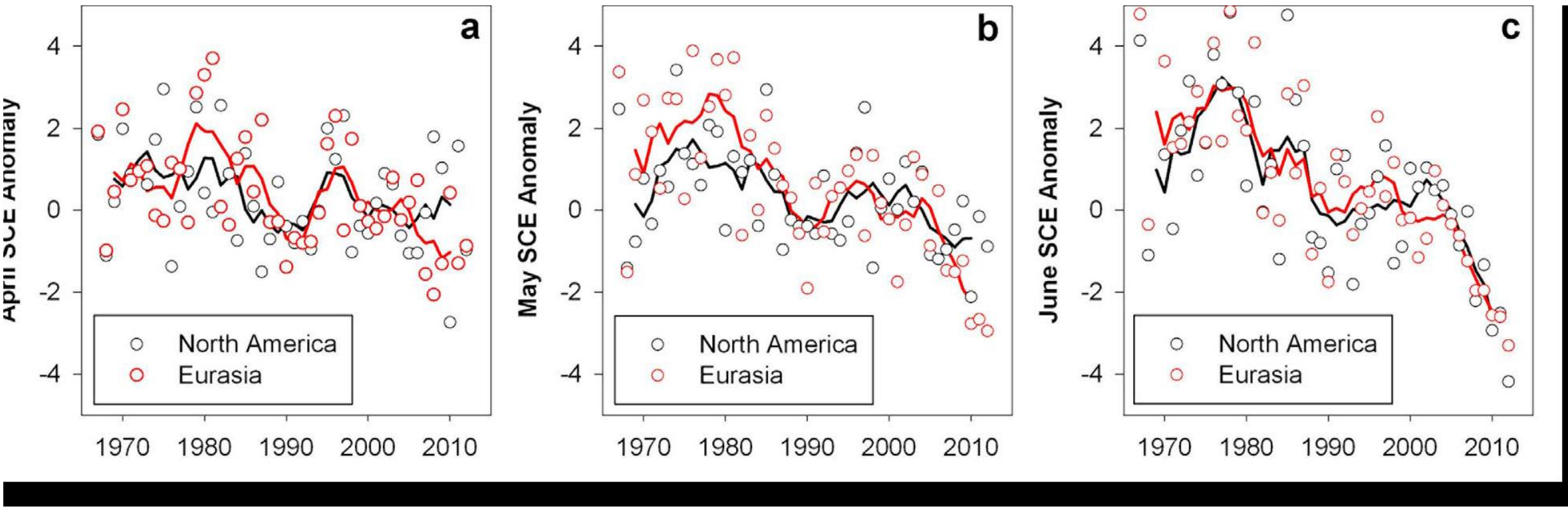
4 December 2012

Earth Observation and Cryosphere Science Conference: Status of Snow Activities

- **CoReH2O: An Earth Explorer candidate mission for the SWE mapping with X/Ku-band SAR**
- **CAL/VAL including development of new missions and products for snow monitoring from current satellite systems (optical and microwave)**
  - Canadian experiments (Churchill)
  - Finnish experiment and sites (Sodankylä)
  - SIOS initiative at Svalbard
- **Methodology development for SWE and FSC mapping (+ albedo) including techniques for forested areas**
  - Snow grain size and model development
  - Potential of SAR interferometry
- **Monitoring of terrestrial cryosphere in global and regional scale**
- **New applications including black carbon in snow and its effect to radiation balance**
- **Comparisons with climate model predictions**

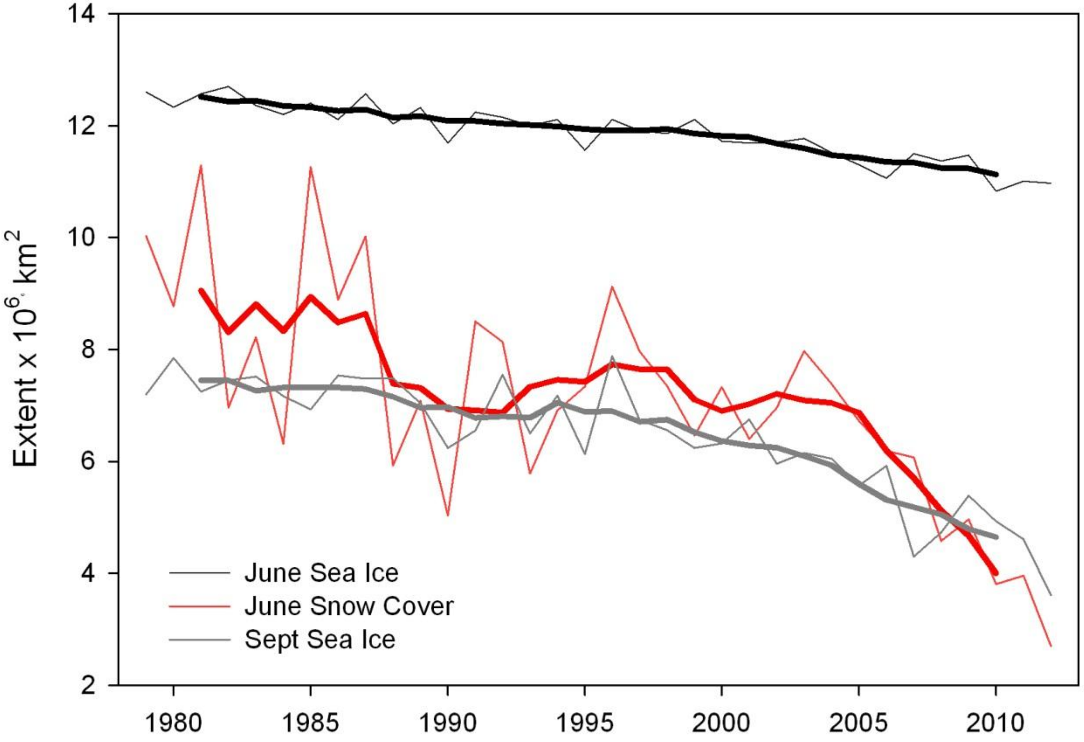
Trends of Snow extent based on optical satellite data



Derksen, C., and R. Brown (2012), Spring snow cover extent reductions in the 2008–2012 period exceeding climate model projections, Geophys. Res. Lett., 39, L19504, doi:10.1029/2012GL053387.

Changes in Snow vs. Sea Ice Extent

Northern hemisphere June snow cover and Arctic sea ice extent, 1979-2012



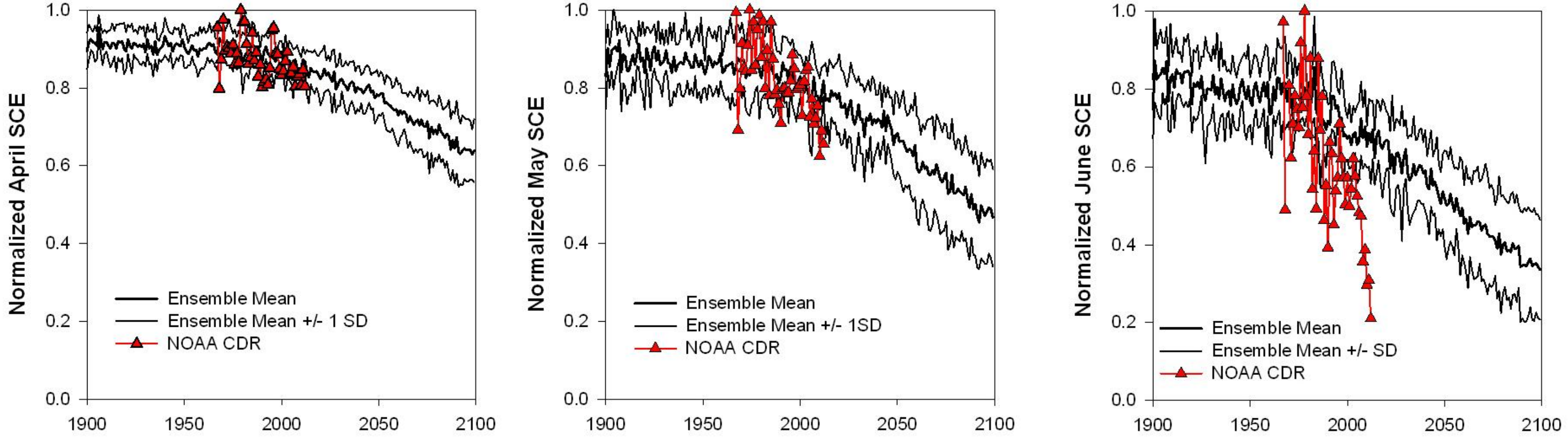
- For the 1979 – 2012 time period, June snow extent is decreasing at a rate of -17.6% per decade (relative to 1979-2010 mean).
- September sea ice extent is decreasing at -13.0% per decade.

Environment Canada Environnement Canada

Derksen, C Brown, R (2012) GRL

Canada

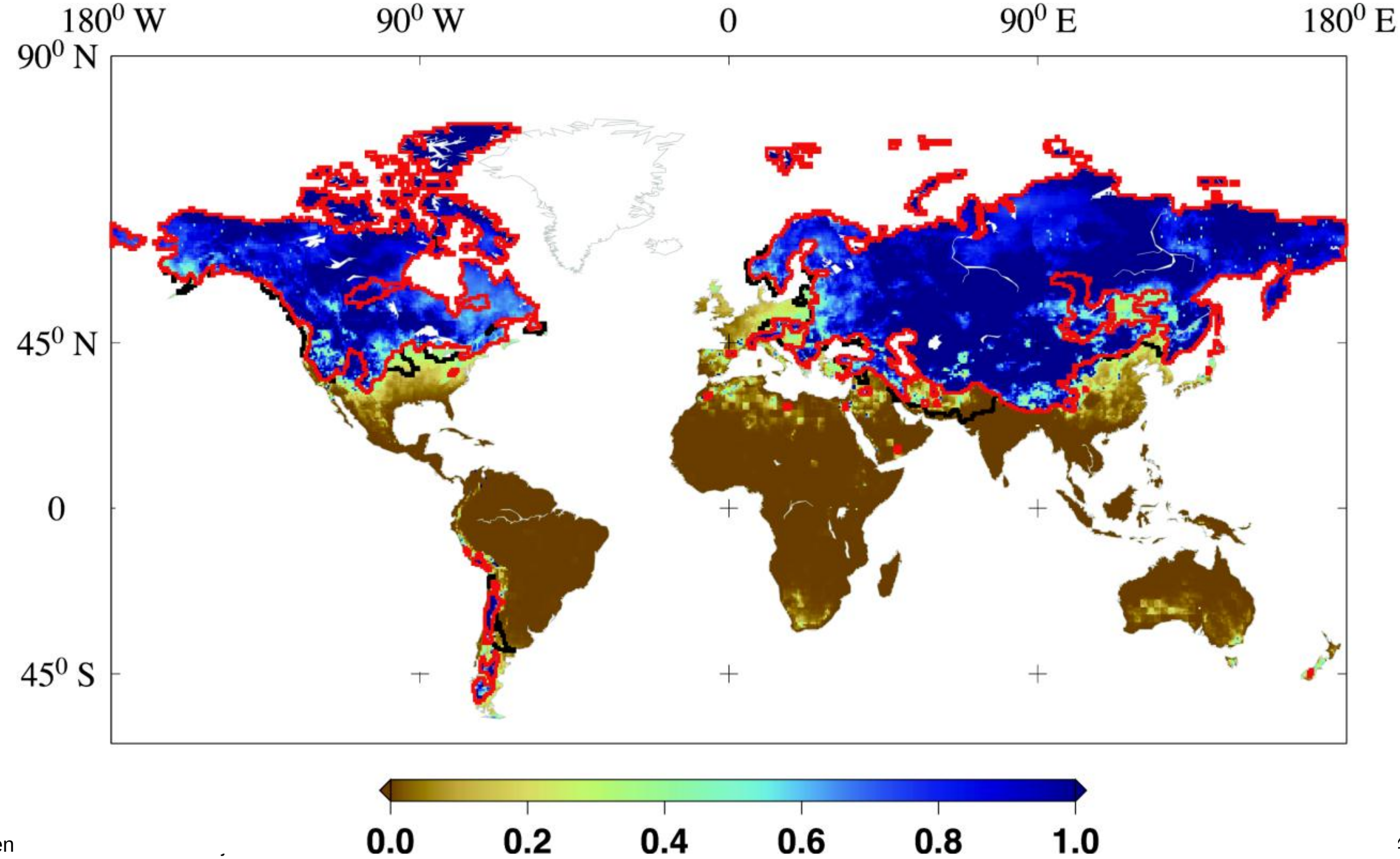
Simulated vs. Observed Arctic Snow Cover – CMIP5



Historical + projected (8 CMIP5 models; rcp85 scenario) and observed (NOAA snow chart CDR) snow cover extent for April, May and June for land areas north of 60°. Snow covered area is normalized by the maximum area simulated by each model.

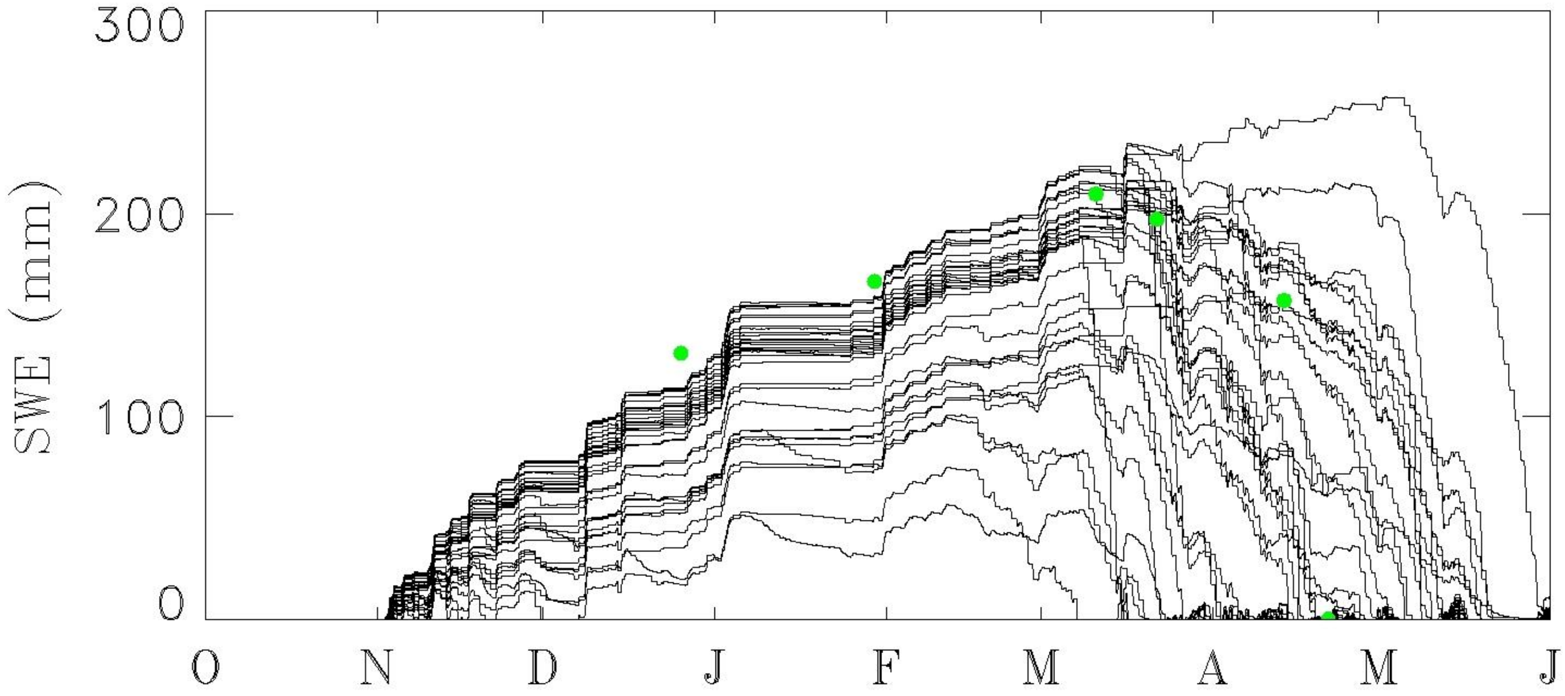
- NOAA observations are mostly within ±1 standard deviation of the multi-model ensemble in April and May, but start to diverge from the model consensus in recent years.
- Marked reductions in June SCE observed since 2005 fall below the zone of model consensus defined by +/-1 standard deviation from the multi-model ensemble mean.

- **Streamflow dominated by snowmelt within areas enclosed by the red lines.**
- **Black lines delineate additional areas where water availability is strongly influenced by snowmelt.C**
- **Colour scale indicates the ratio of accumulated annual snowfall divided by annual runoff [modified from Barnett et al., 2005].**



Current uncertainties in snow processes modeling

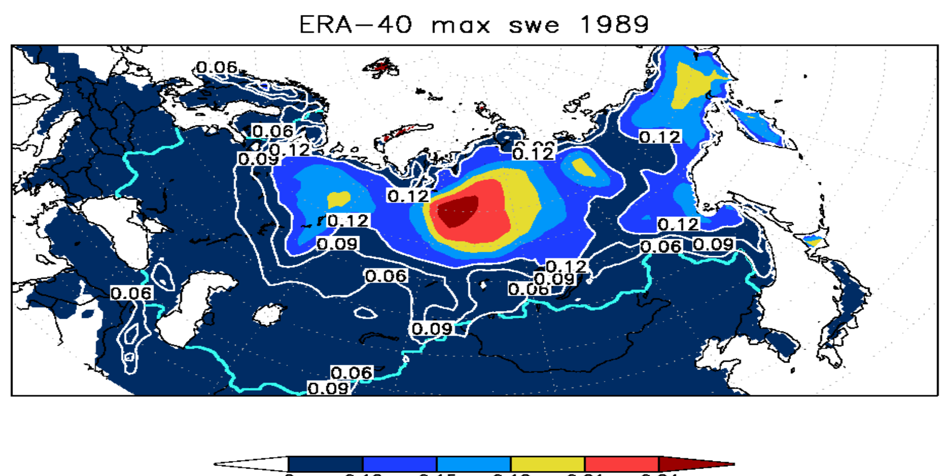
- Uncertainty in snow process modelling according to comparison of 33 point models (lines) and SWE measured in snow pits (green dots) at Fraser, Colorado, USA in winter 2003–-2004 (Rutter et al., 2009).



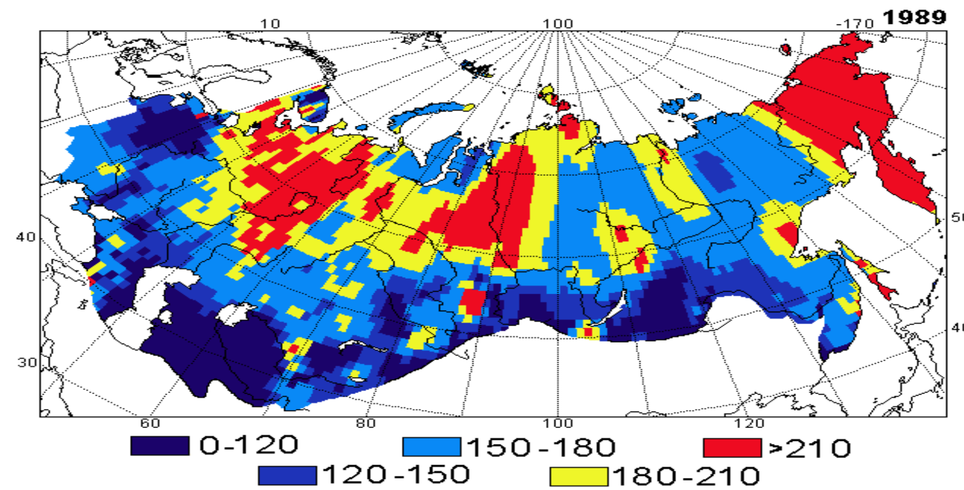
Deficits of re-analysis data and ground data interpolation

- ERA-40 re-analysis data of ECMWF:
  - Maximum SWE in 1989

  (SWE = snow water equivalent indicating the total amount of snow)



- Corresponding INTAS-SCCONE Russian ground based observations (SWE from 210 snow courses around northern Eurasia)



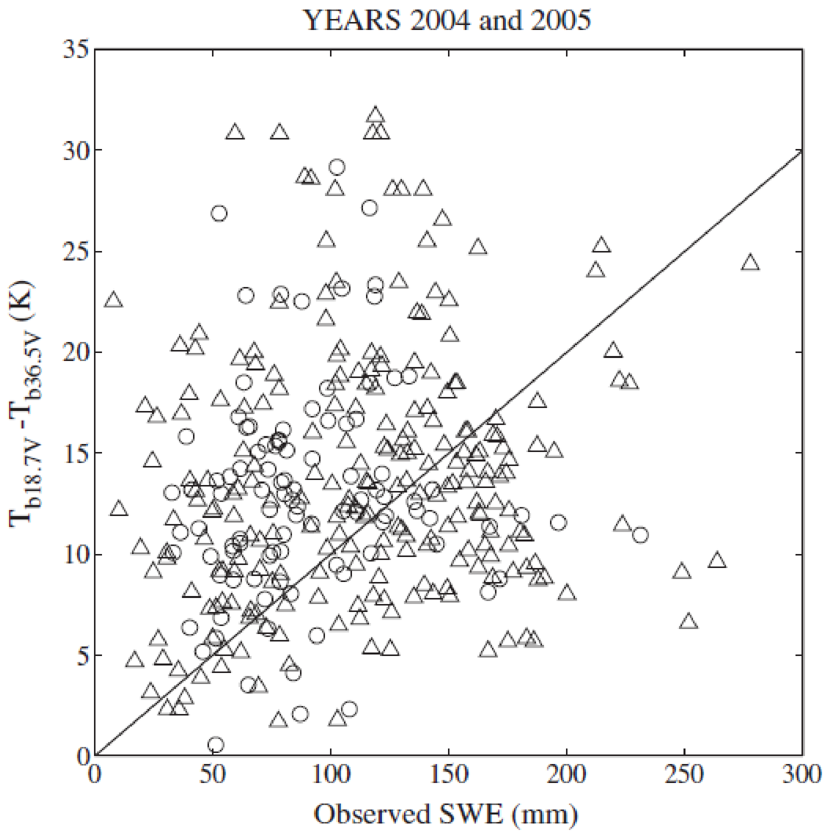
Mapping of SWE on a global scale

Typical algorithms for SWE retrieval from passive microwave data based on linear regression; hard to apply consistently on global scale

- Regional variability in land cover, snow properties
- Temporal variability (snowpack evolution)

SWE retrieval through application of snowpack emission models offers possibility to correct for some effects hindering traditional models

- Variations in density, grain size, temperature etc.
- Effects of snow stratigraphy

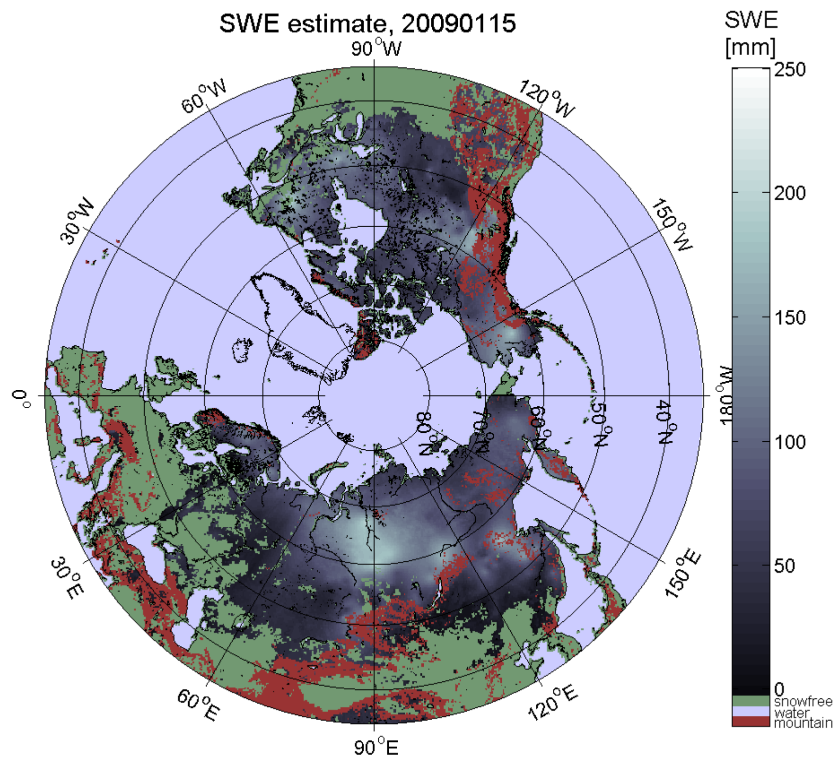


AMSR-E data derived spectral difference index (Tb,18.7V−Tb,36.5V) against observed SWE value at snow courses in Finland. Circles = 2004; triangles = 2005 (Pulliainen, 2006, *RSE*).

Current state-of-art observational methods for the assessment of snow mass (RMSE: 30 - 50 mm)

Current global monitoring of SWE relies largely on passive microwave observations:

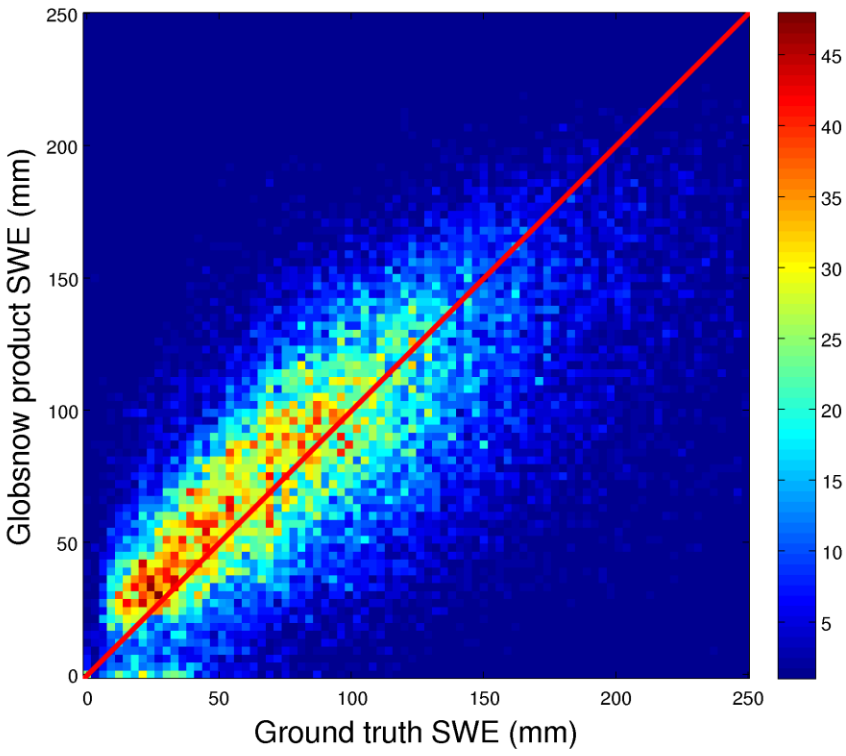
- Reasonable SWE retrievals can be obtained *regionally* using empirically defined algorithms
- Stand-alone hemispheric scale empirical algorithms exhibit serious spatial and temporal biases
- Also algorithms based on emission model inversion and data assimilation (e.g. ESA GlobSnow) suffer from drawbacks emrging from the coarse resolution passive microwave observations

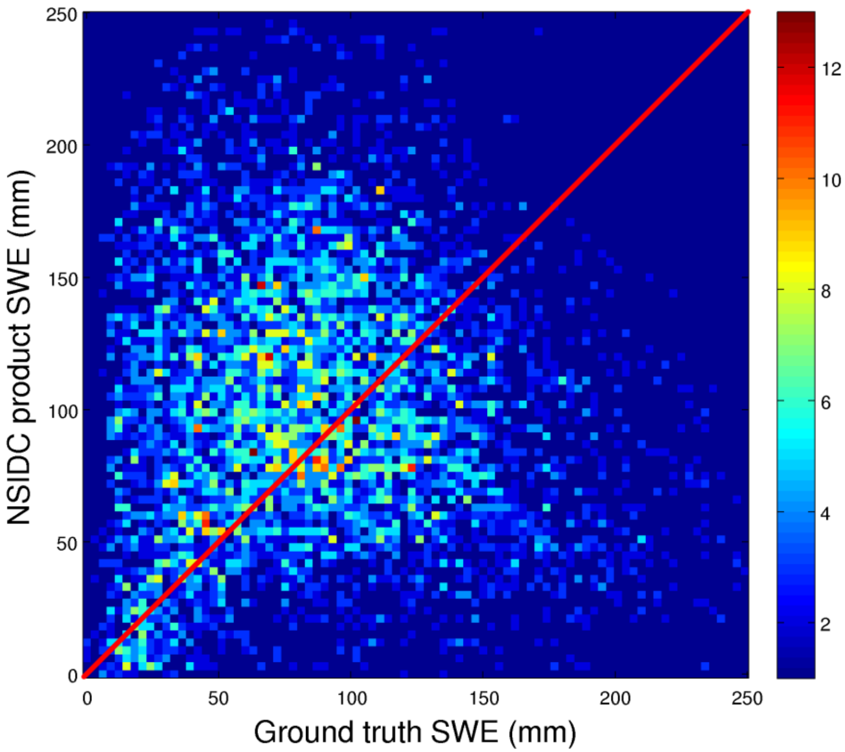


An example of the ESA DUE *GlobSnow* SWE product for 15 January 2009. Mountainous areas masked.

SWE retrieval accuracy (I)

- **Density scatterplot**
- **Ground truth data is INTAS SCCONE SWE path data**





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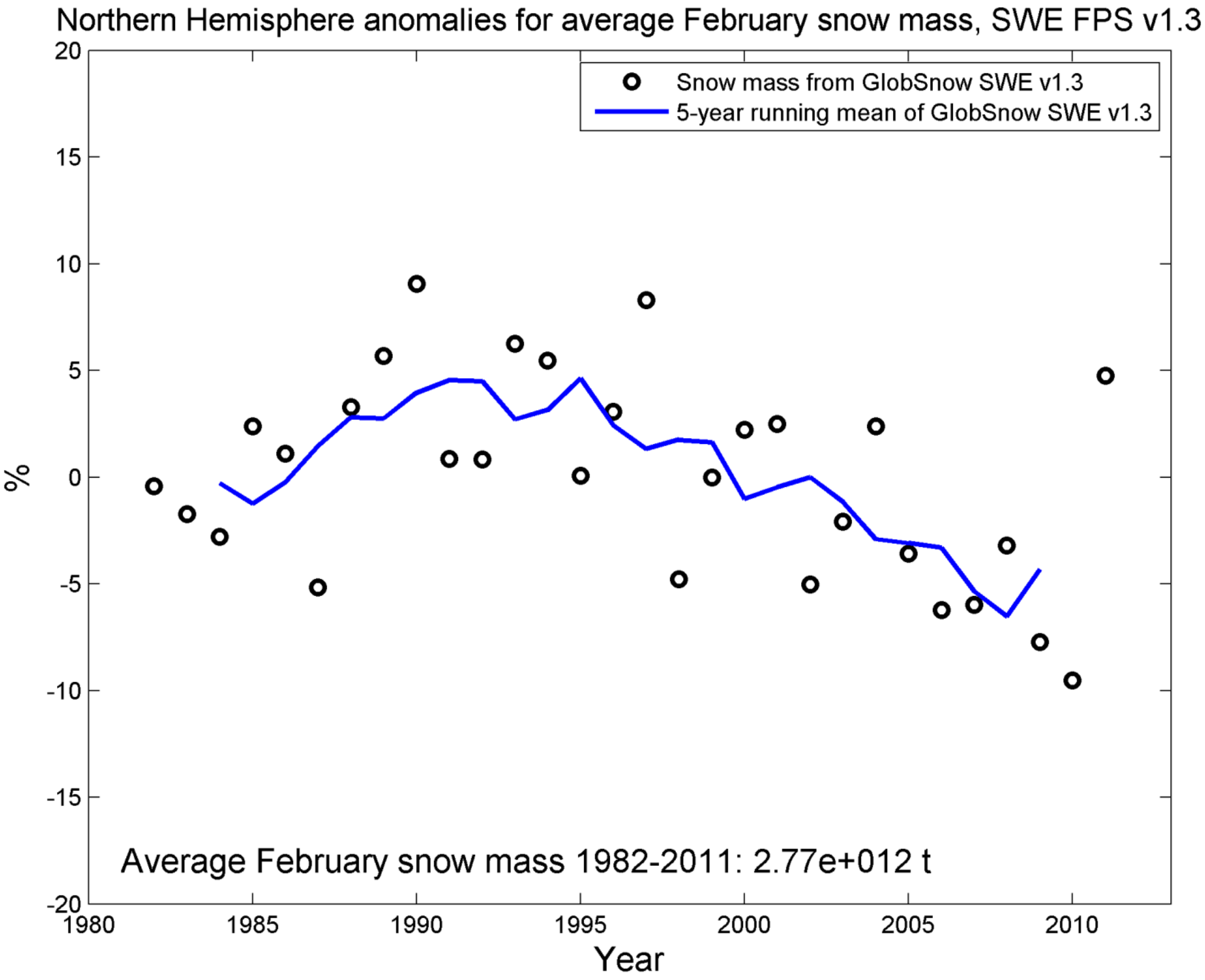
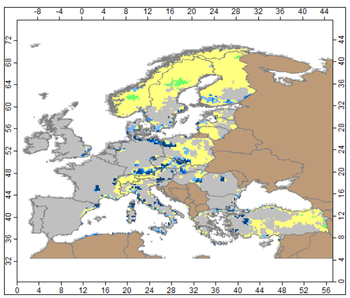
Trend of hemispheric snow mass



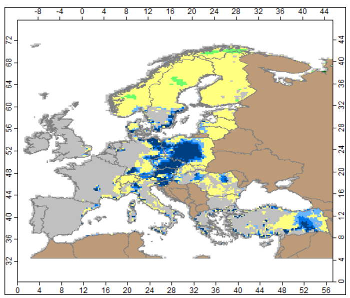
Indexes for climate change and hydrology: Use of SWE information

- SSPI: Standardized SnowPack Index as indicator for drought

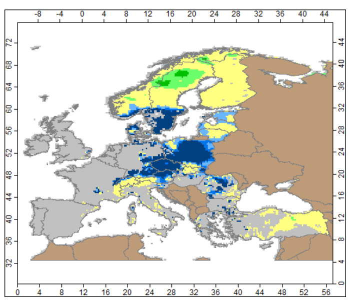
Monthly Average SSPI Winter 2005 - 2006



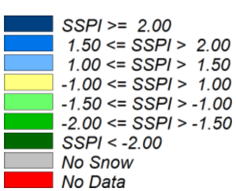
December 2005

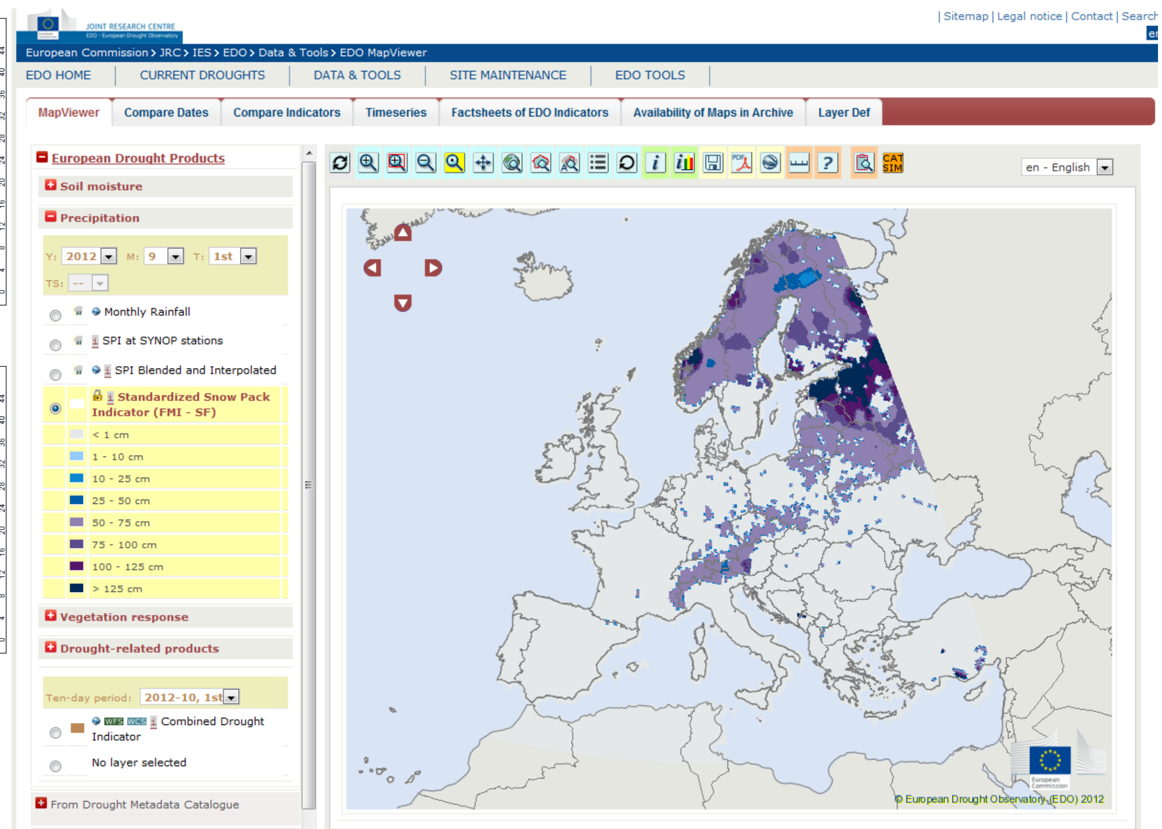


January 2006



March 2006





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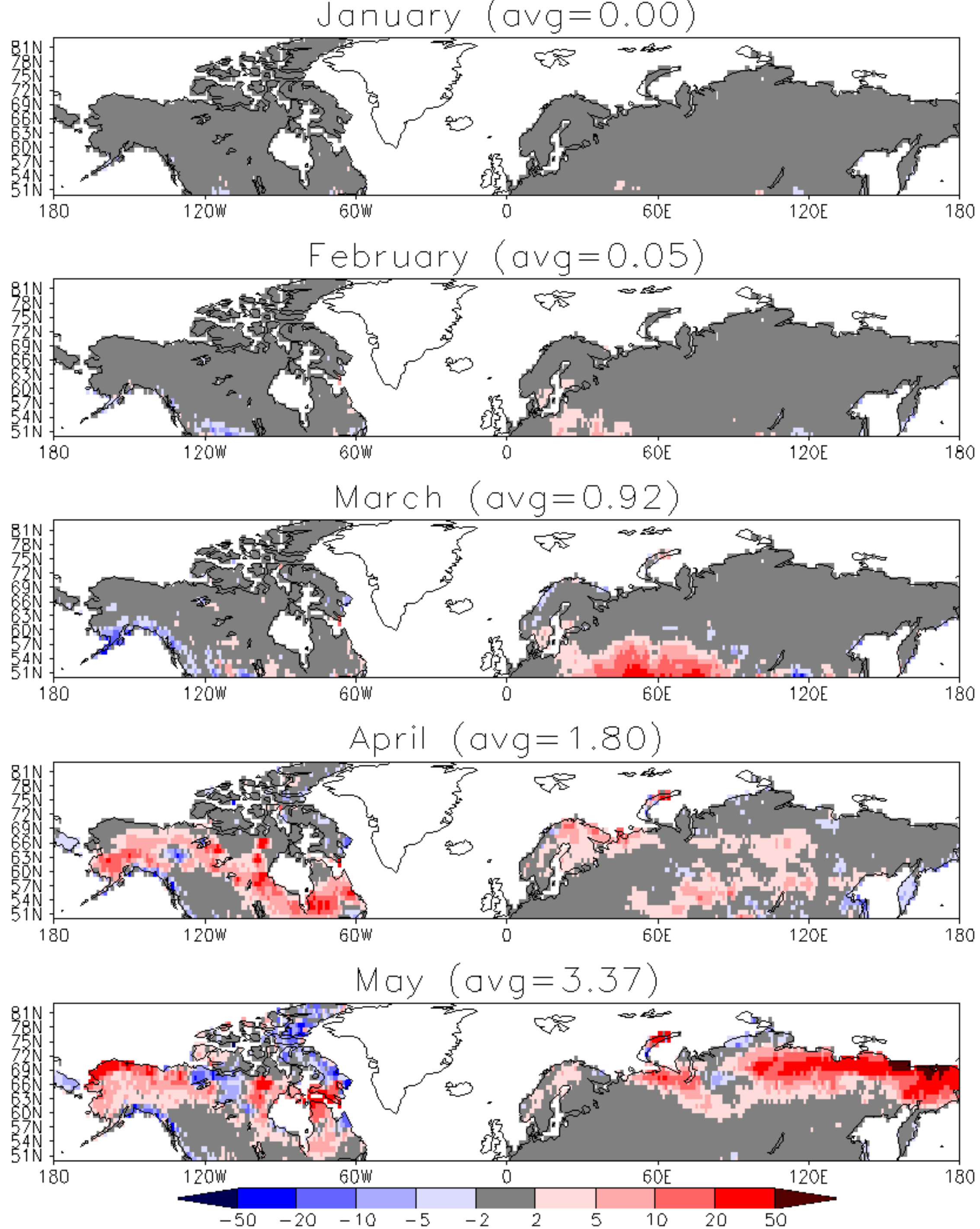
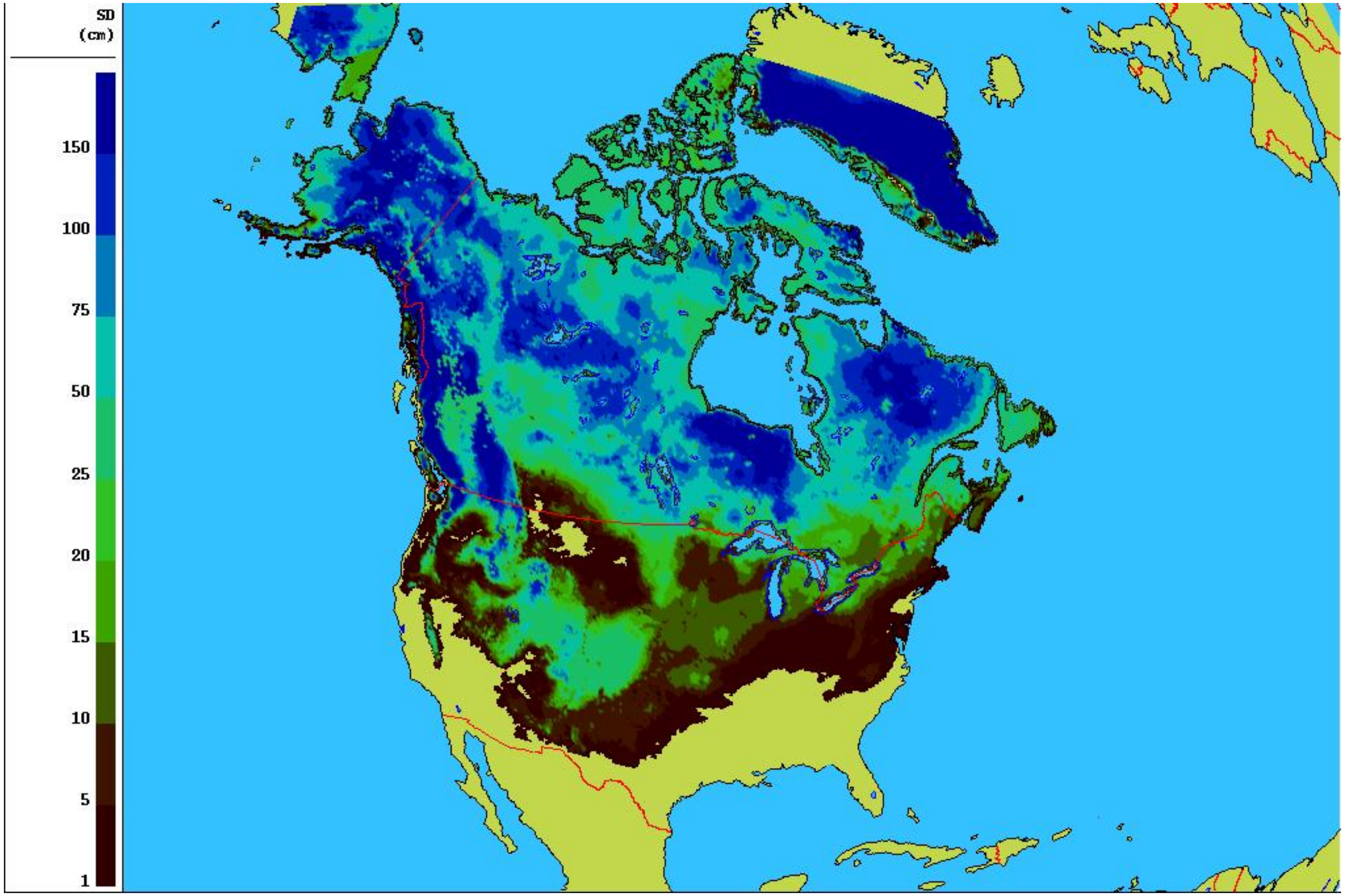
Consequent modelled change of TOA radiation forcing (W/m²) in a period of 28 years for northern land areas

(positive values indicating the warming effect)



Assimilation of Satellite Data Derived SWE to Canadian CALDAS (Land Data Assimilation in NWP)



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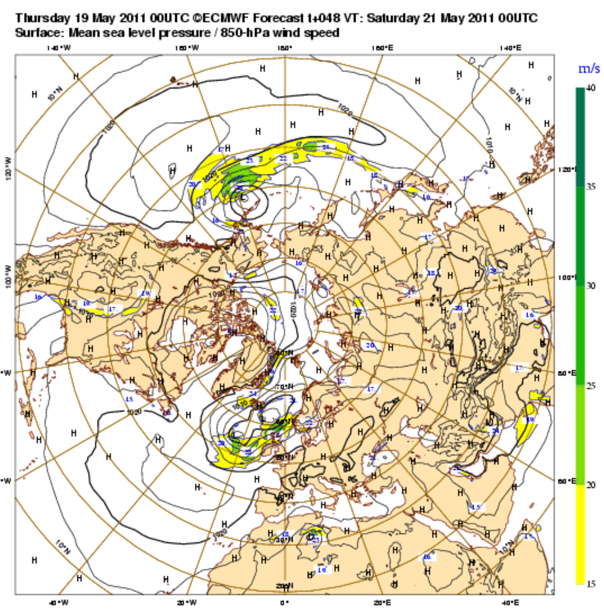
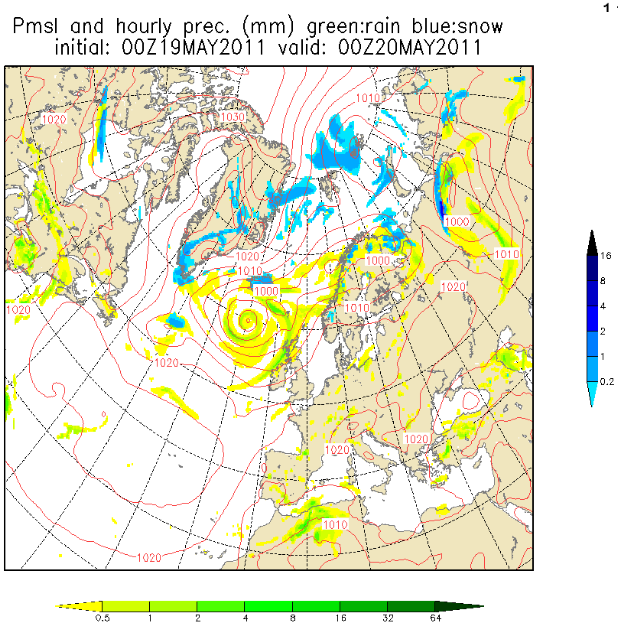
Development of resolution in global and regional NWP models

⇒ Need of surface forcing data of a higher resolution/higher resolution modeling of surface processes and/or downscaling of coarse resolution data

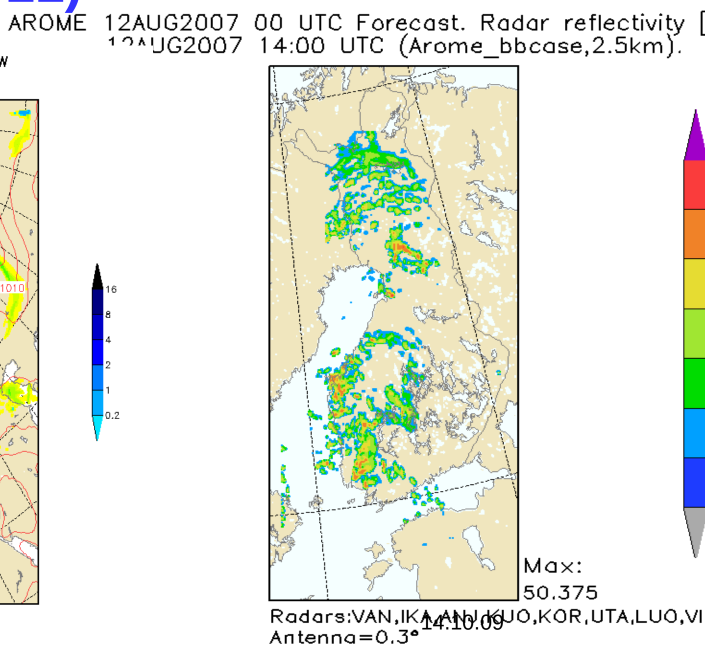
ECMWF
17km → 10km (2015)



HIRLAM
16km → 7.5km (2011)



HARMONIE
2.5km → ~1km

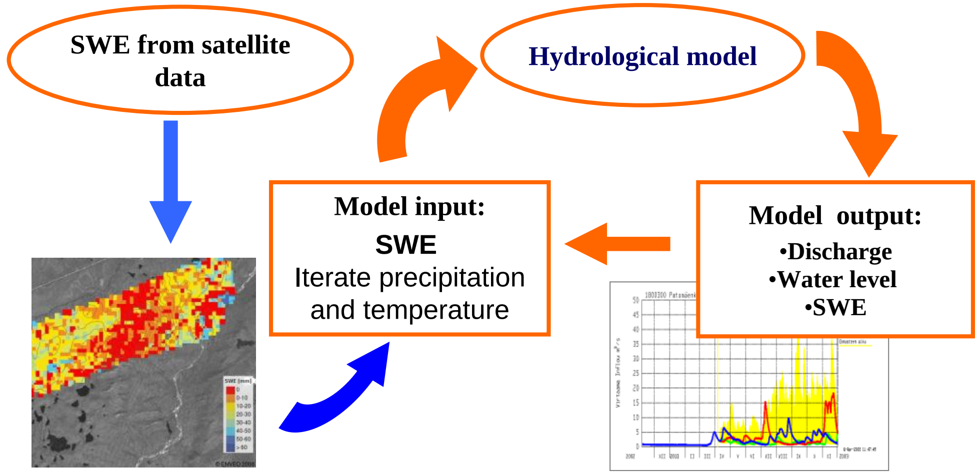


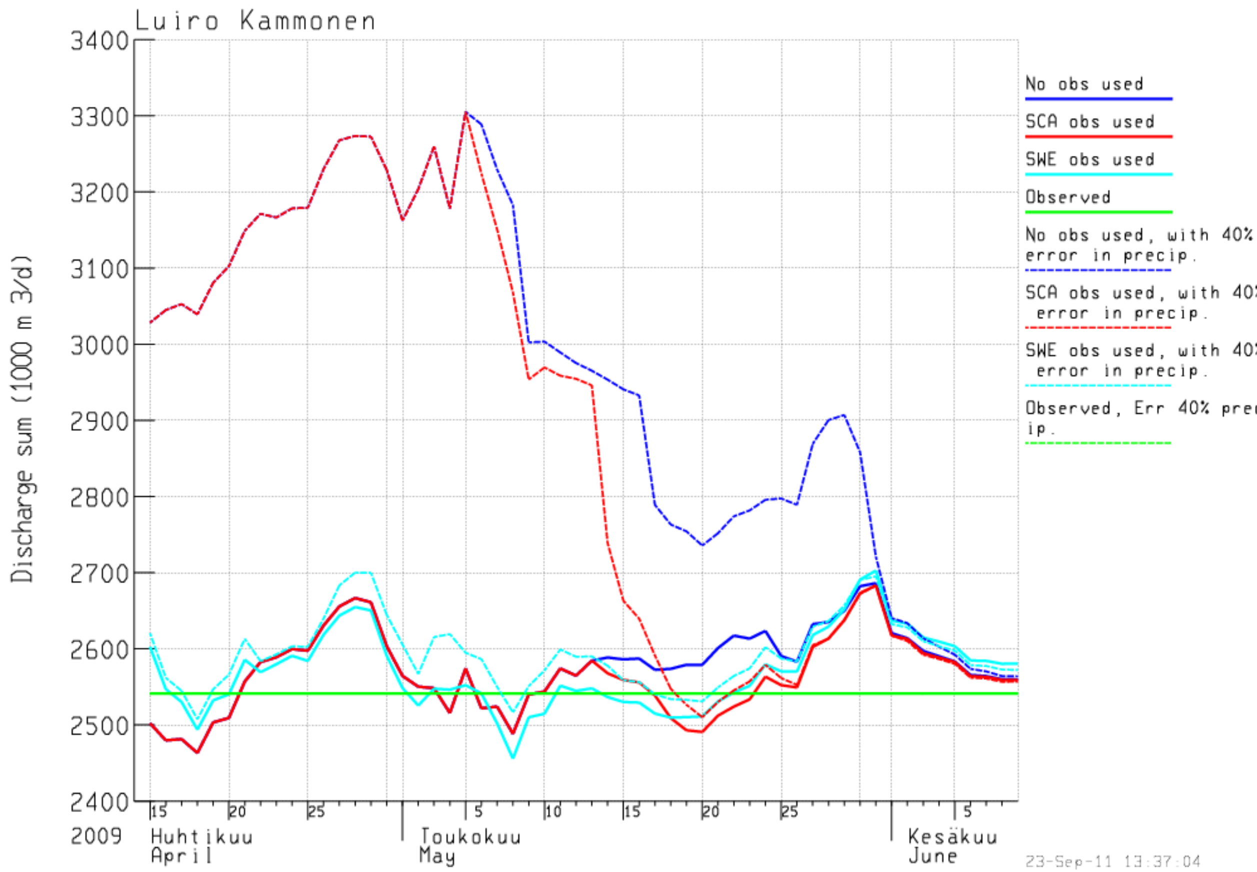
What is the spatial variability of SWE within a scale of passive observations (~25 km)

- **Varies for different eco/snow -regions (typical max. levels of SWE given in parenthesis according to Sturm et al. 1995):**

1. **Boreal forests (globally the largest snow region, 80-300 mm)**
   - Small to modest variability mainly related to the variability of land cover and forest density (variability typically high within a 25 km pixel)
   - Spatially distributed *in situ* for the NoSREx test site ("classical" boreal forest site at Sodankylä) ranging e.g. from ***85 to 155 mm*** in typical conditions
2. **Tundra (characteristically a low level of precipitation, 40-280 mm)**
   - Modest to high variability related to topography (wind effects)
   - Values observed for NoSREx/Saariselkä site (alpine tundra, Finland) ranging e.g. from ***15 to 500 mm***, experiments in Canadian tundra from ***30-200+ mm***
3. **Prairie/Steppe (0-180 mm)**
   - Modest to high variability related to topography (wind effects)
4. **Alpine mountains (200-750 mm)**
   - High levels/variability due to slopes/wind effects and high precipitation
5. **Maritime (250-1700 mm)**
   - High levels/variability due to high precipitation

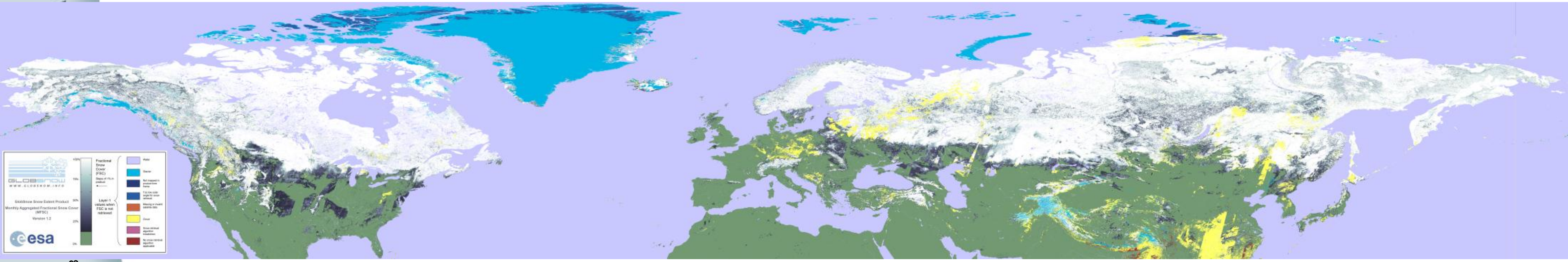
Assimilation of satellite data-derived SE and SWE to hydrological modeling





Activities in ESA DUE-GlobSnow

- GlobSnow provides long term datasets (15-30 years) on Snow Extent (SE) and Snow Water Equivalent (SWE) for climate research purposes.
- SYKE's *SCAmod* method for fractional snow cover mapping implemented for Northern hemisphere -> GlobSnow Snow SE-product
- Based on Envisat/AATSR and ERS-2/ATSR-2
- Cloud detection algorithm developed at SYKE, contributed by ENVEO, Austria



- Operational production at the Finnish Meteorological Institute (FMI)

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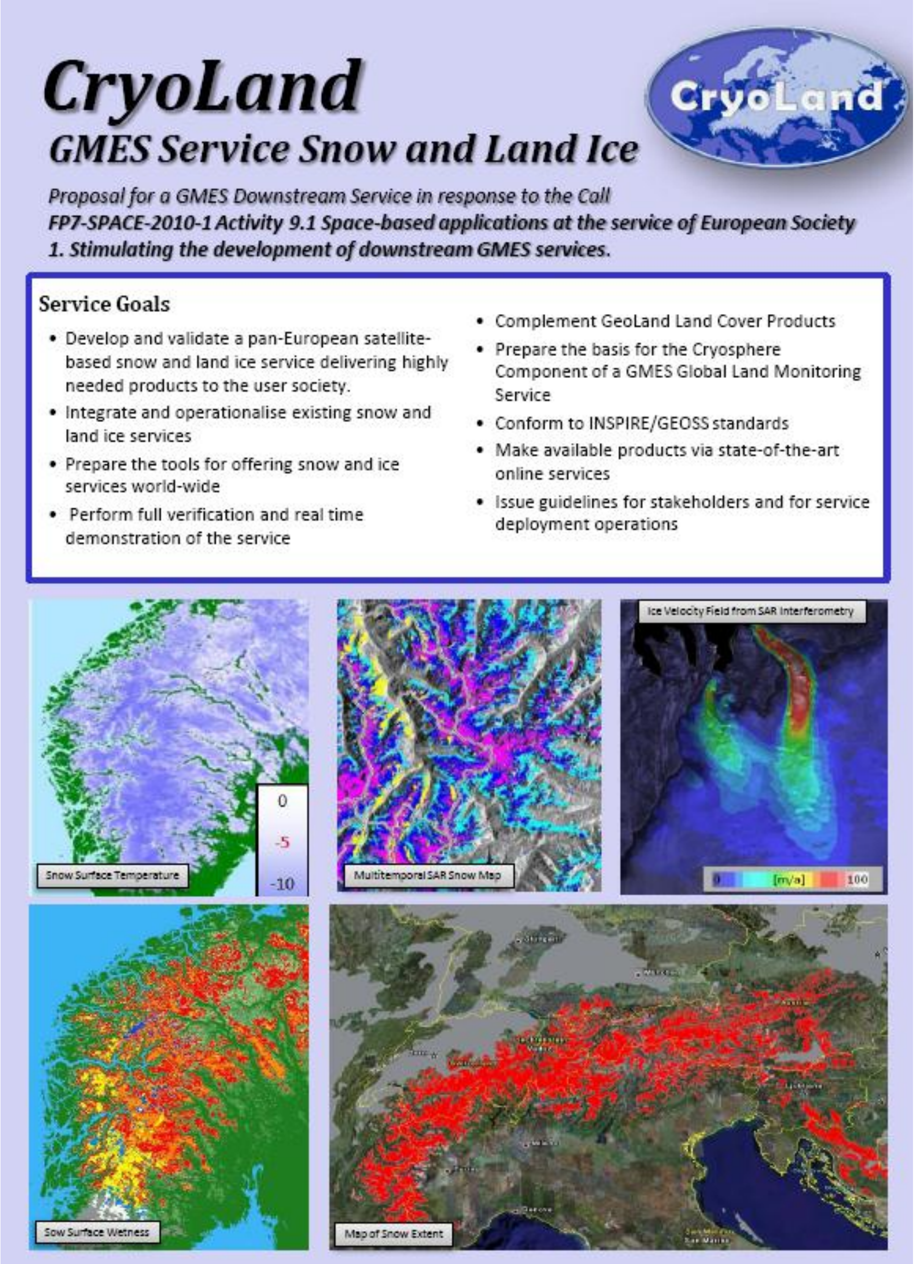
EUMETSAT: H-SAF

- FMI is responsible to the development of real-time snow mapping services for Europe
  - SWE mapping approach is based on the further development of GlobSnow system

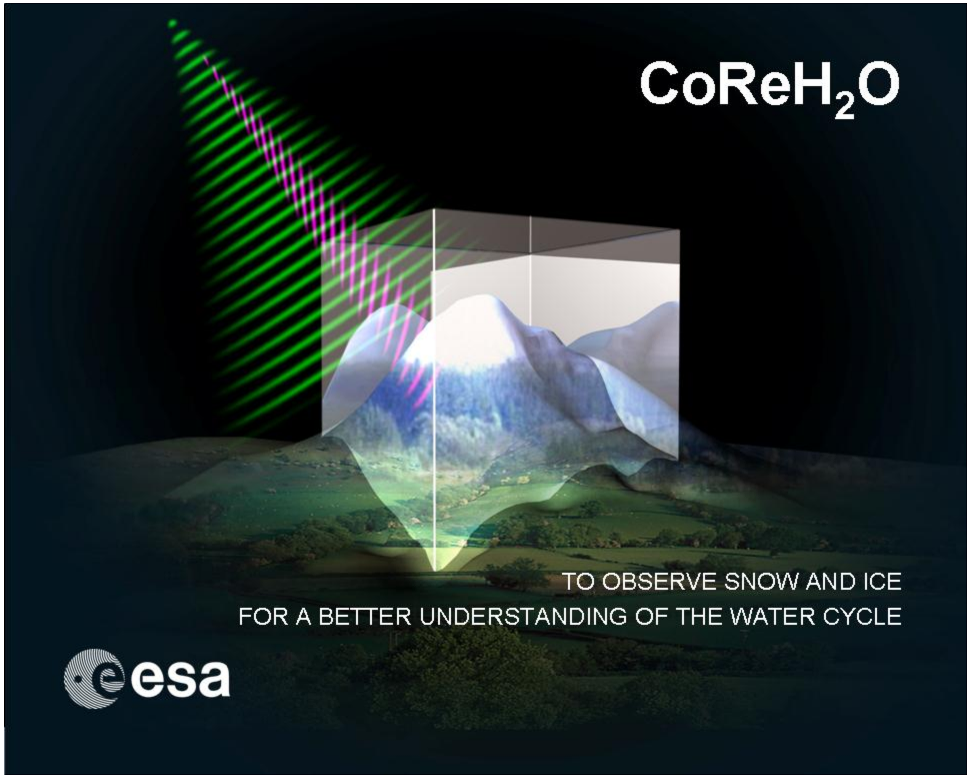
EC: CryoLand

- Multinational EC project carrying partially on with GlobSnow efforts
  - Development of operational satellite-based snow & land ice products

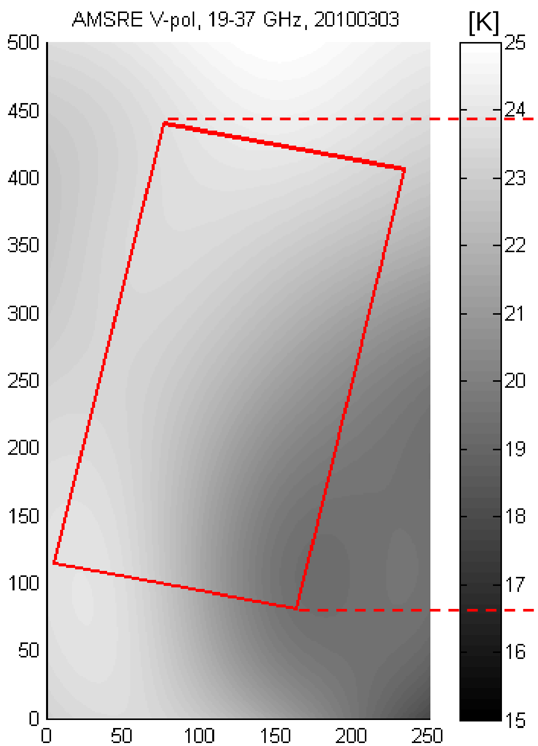


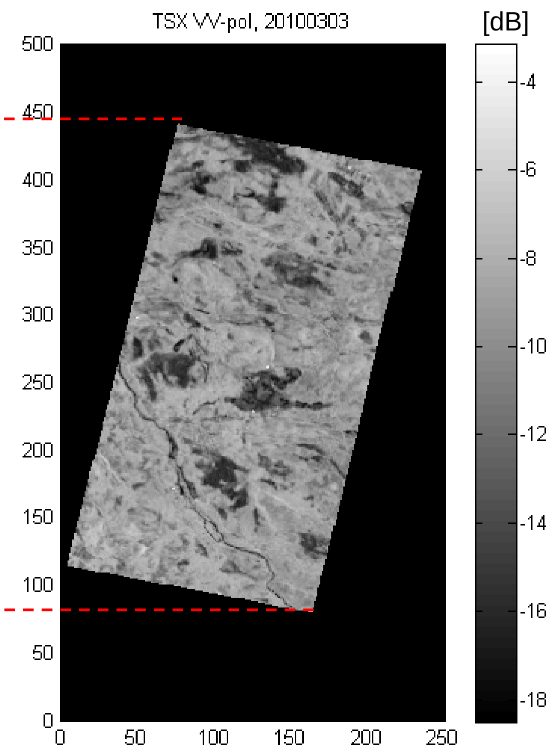
ESA CoReH2O preparation work

- Cold Regions Hydrology High-resolution Observatory
- Dual frequency (X / Ku–band) SAR for cryospheric mapping: **SWE** in particular
- ESA Earth Explorer candidate - Phase A (decision for launch early 2013)
- Preparatory work includes several science projects with extensive campaign activities at Sodankylä, Finland; Churchill/North West Territories; Canada; Alps, Austria



Contrast of scale: passive microwave and SAR





AMSRE 19-37 GHz, Vpol brightness temperature (spline interpolated from 25 km EASE grid cells)

TerraSAR-X VV-pol backscatter (aggregated to 25 m resolution)

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SWE maps

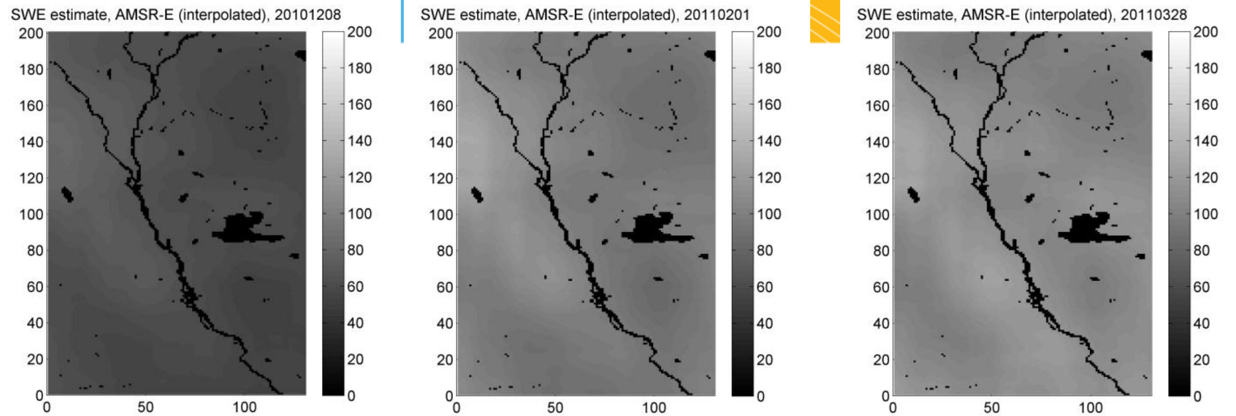
- All maps based on iterative inversion of forward modes (SWE as free parameter)
- Blended inversion applies estimates of statistical uncertainties of various data sources (observations)
- Effective grain size used for model regularization

$$F(SWE,d_0)=\sum_{k=1}^{P_1}\frac{1}{2\sigma_k^2}\left[\Phi_k(SWE_k,x_1,\ldots x_w)-\sigma^o{}_k\right]^2$$

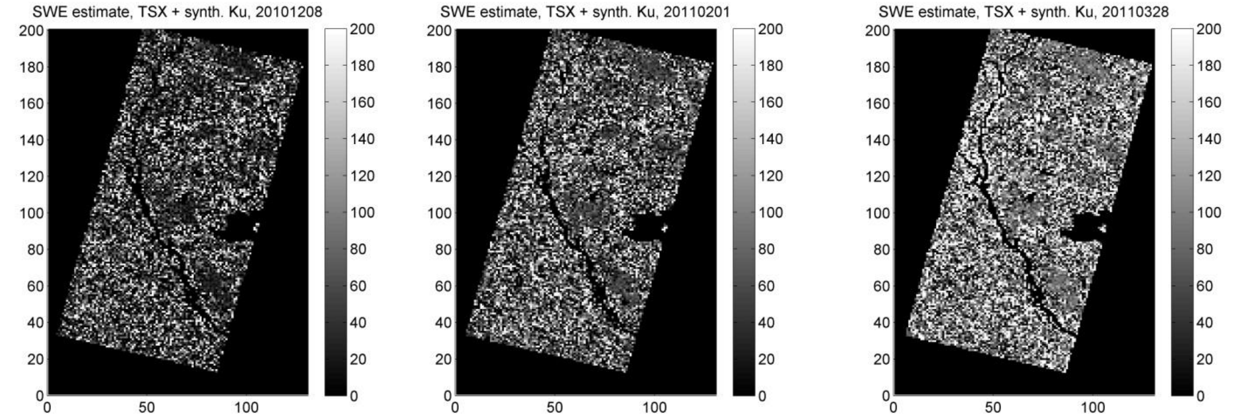
$$+\sum_{k=1}^{P_2}\frac{1}{2\lambda_k^2}\left[\Psi_k(SWE,x'_1,\ldots x'_w)-T_{b,k}\right]^2$$

$$+\frac{1}{2\,\mathrm{var}(d_0)}\left[d_0-\langle d_0\rangle\right]^2$$

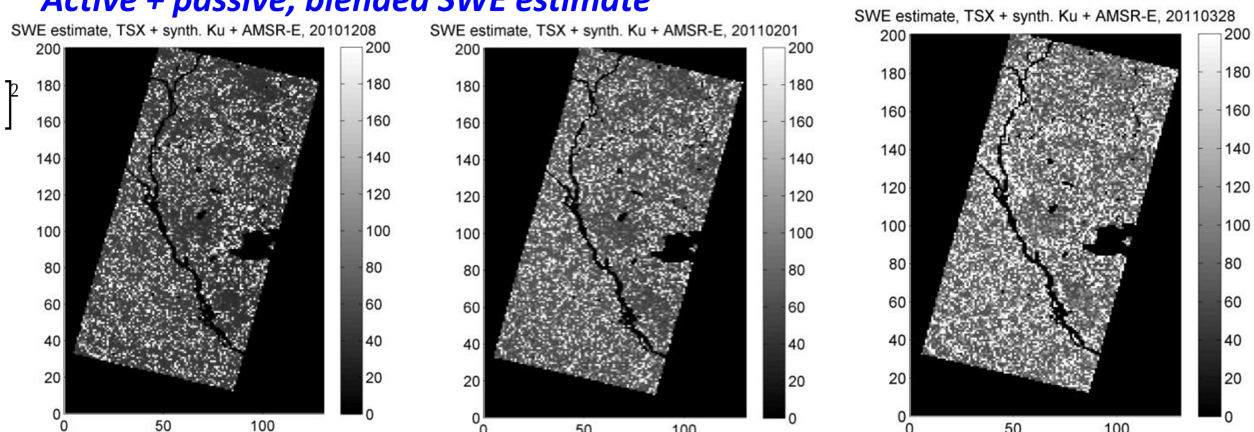
Passive microwave (water mask applied)



Active microwave



Active + passive, blended SWE estimate



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Example on Cryospheric CAL-VAL Activities: Sodankylä-Pallas Super Site

- Reference instruments for various EO missions:
  - ELBARA-II of ESA : Reference for SMOS (global soil moisture and ocean salinity)
  - SnowScat of ESA: Reference for the planned CoReH2O SWE mapping SAR mission
  - SodRad: Reference for SSMI/I and AMSR-E
  - Mast-based spectrometer: Reference for MODIS, MERIS etc.
  - Reference systems NASA EOS Aura OMI, ESA Envisat GOMOS
  - Jaxa GOSAT

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Tower-based measurements of seasonally snow-covered terrain

Passive microwave:

October, 2009 – ongoing (L-band)

December, 2009 – ongoing (C, X, Ka, W-bands)

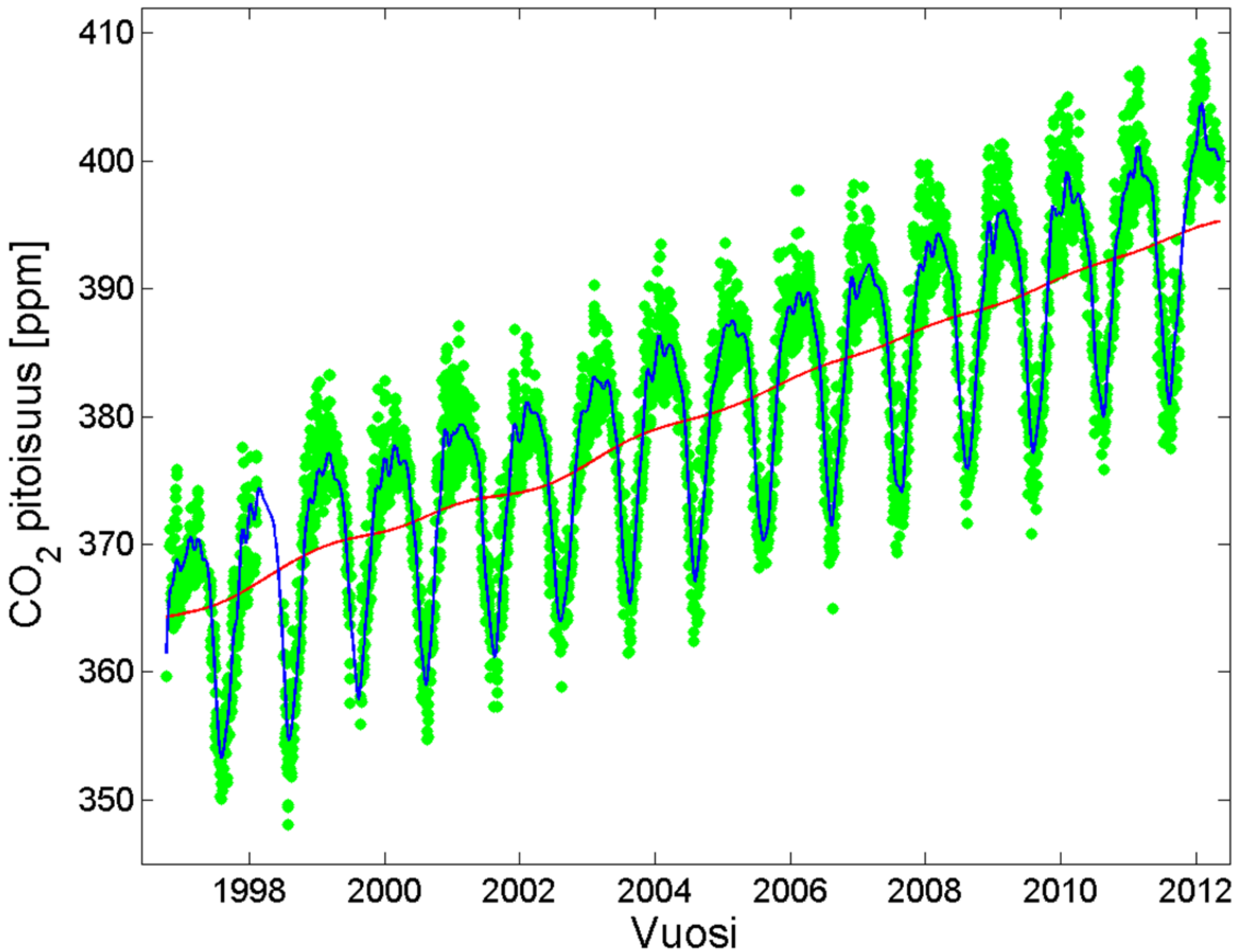
Active microwave:

October, 2009 – ongoing

VIS/IR (spectroradiometry):

Started 2008

CO_2 concentration at Pallas



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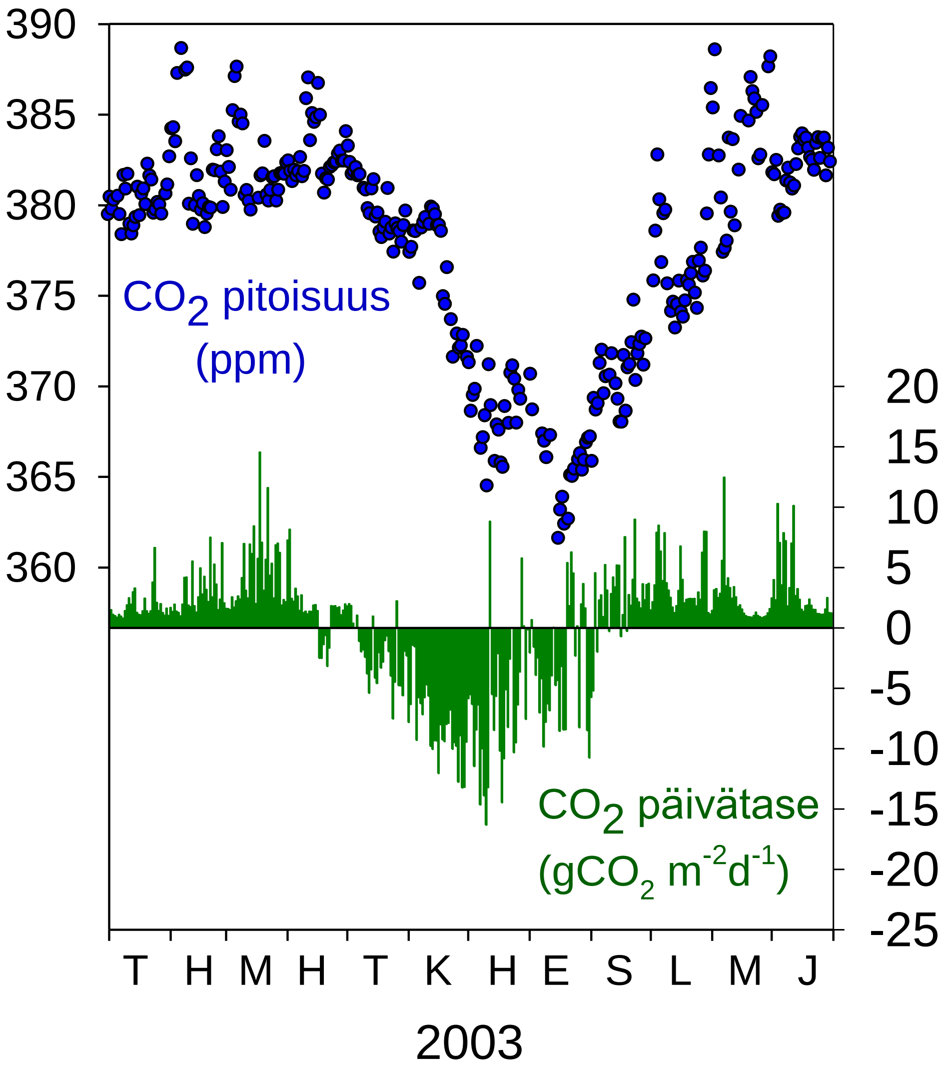
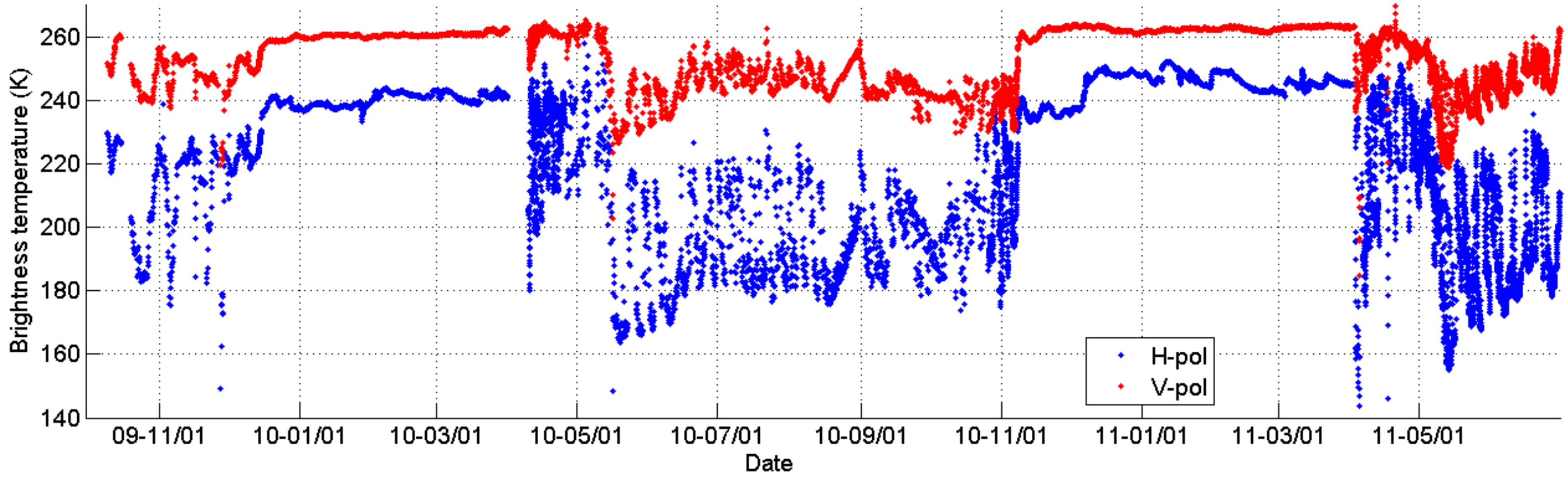
CO_2 concentration and daily fluxes at Pallas (north boreal spruce forest)

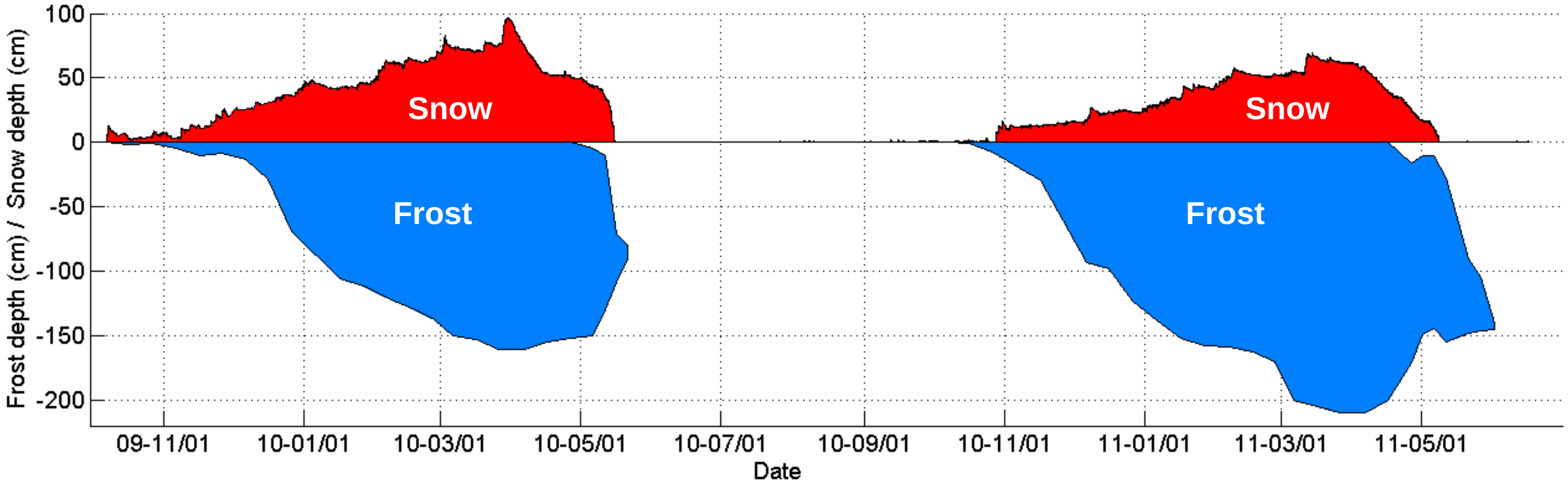


SodRad and ESA-Elbara-II: References for space-borne radiometers

Two winter time-series: ELBARA-II and frost/snow



Inc. angle: 50°

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