VALUE OF IN-SITU AND SATELLITE BASED SNOW OBSERVATIONS FOR IMPROVING SEASONAL RUNOFF PREDICTIONS

(work in progress)

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**Background**

How to integrating snow observations in seasonal runoff predictions for hydropower management?

- Currently and in the past - numerous projects with Swedish hydropower industry (Elforsk/HUVA)

**EU FP7 CryoLand 2011-2015**

- Products and Services for satellite based Snow and Land Ice data

**Data integration**

- Tools for integration of CryoLand snow products in hydrological models:
  - download, pre-process, assimilation

**Hydrological modelling**

- Evaluate impact on stream flow simulations of assimilating satellite snow data
In-situ data case-study: assimilation in seasonal hydrological forecasts

• High resolution SWE data along representative measurement lines

• Spatial interpolation to hydropower reservoir basins

• Spring melt forecasts (15 April-31 July):
  • Ensembles of historical years/ECMWF seasonal forecasts (v4?)
  • Improved by updating model snow storage to the interpolated in-situ data

• Not consistent year-to-year.

Gustafsson et al, 2009-2012: NHC2012
Operational observations of snow and the use of these observations in Sweden?

- Daily snow depth observations by SMHI at ~600 stations:

- ~20 Annual snow courses by hydropower companies
- ~10² km Helicopter GPR surveys (by Vattenfall AB)

- Bi-weekly observation of depth, density and SWE by hydropower companies (VRF AB) at ~50 reservoir dams:

- Snow-mobile GPR surveys 2007-2015 (~30km by KTH/SMHI/SU/VRF)
Deviation in mean snow depth (mod vs obs)
601 stations
Correlation analysis
Snow depth correlation higher North-South than East-West
Cryoland Case-study: Sweden

Hydrological model S-HYPE
- Swedish operational application of HYPE model

CryoLand satellite snow products used in the study:
- **Pan-European Snow Water Equivalent (SWE) - FMI**
  - Satellite-based microwave radiometer data (DMSP SSM/I) and weather station snow depth data
  - Pixel size 0.1° x 0.1° (~10x10km²)

- **Pan-European Fractional Snow Cover (FSC) – ENVEO/SYKE**
  - Optical satellite data (MODIS/Terra)
  - Pixel size 0.005° x 0.005° (~500x500m²)

- **Scandinavian Multi-temporal FSC products - NR/NORUT**
  - Multi-temporal (latest cloud-free information last 7 days)
  - MODIS/Terra (250x250m²)

- Daily data 2011-2013
- Pan-European area: 72°N / 11°W to 35°N / 50°E.
CryoLand SWE vs S-HYPE modellen
Pan-European SWE product (FMI)

- **Good agreement** in central part of middle and northern Sweden:
  - Forests
  - Non-mountain areas

- **Correlation is high** (except for the south)

- **Variability and Mean value differs:**
  - In the south (little snow and lakes)
  - along the east coast
  - western mountain range

- **Problem for the satellite or model?**
  - Mountains, surface water, coastal areas, areas with small amount of snow
In general a very good agreement between model and satellite data throughout Sweden.

However, the temporal variability is different in the most alpine part of the mountains in northern Sweden.

Transmissivity model is well-adapted to boreal forests.
Assimilation experiment

- 9 non-regulated basins with discharge observations
- Rather small (~1000 km²)
- Distributed on “good” and “bad” areas according to previous comparison

- 5 types of simulations:
  1) Deterministic (single simulation)
  2) Ensemble without assimilation
     - 100 ensemble members
     - Random perturbation on P and T
  3-5) EnKF assimilation with
     3) SWE
     4) FSC (optical)
     5) FSCM (multi-temporal optical)

Test-basins represent:
10-85% forest cover
40-950 m.a.s.l (mean)
7-1100 km²
Good example: Abiskojokki, northern Sweden.
Both SWE and FSC data improve stream flow simulations.
Bad exmple: Vattholma, south-east Sweden.
FSC data improve stream flow simulations
SWE data deteriorate the stream flow simulations (amount and melt problem)
### Overall impact on river discharge simulations

- Overall, rather small changes - small improvements just by ensemble-mean
- SWE-assimilation reduced the model performance in 7 and improved in 2 cases
- FSC-assimilation improved model performance in 5 cases

<table>
<thead>
<tr>
<th>Simulation</th>
<th>KGE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>Improved/reduced performance (sum)</th>
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</thead>
<tbody>
<tr>
<td>Deterministic</td>
<td>Q</td>
<td>0.44</td>
<td>0.84</td>
<td>0.55</td>
<td>0.67</td>
<td>0.41</td>
<td>0.82</td>
<td>0.82</td>
<td>0.88</td>
<td>0.57</td>
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<tr>
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<td>Q</td>
<td>0.47</td>
<td>0.86</td>
<td>0.53</td>
<td>0.64</td>
<td>0.44</td>
<td>0.85</td>
<td>0.82</td>
<td>0.90</td>
<td>0.56</td>
<td>5 improved, 3 reduced (+2)</td>
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<tr>
<td>EnKF_SWE</td>
<td>Q</td>
<td>0.83</td>
<td>0.80</td>
<td>0.19</td>
<td>0.34</td>
<td>0.55</td>
<td>0.49</td>
<td>0.81</td>
<td>0.53</td>
<td>0.56</td>
<td>2 improved, 7 reduced (-5)</td>
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<tr>
<td>EnKF_FSC</td>
<td>Q</td>
<td>0.61</td>
<td>0.85</td>
<td>0.56</td>
<td>0.72</td>
<td>0.04</td>
<td>0.64</td>
<td>0.82</td>
<td>0.88</td>
<td>0.62</td>
<td>5 improved, 2 reduced (+3)</td>
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<tr>
<td>EnKF_FSCM</td>
<td>Q</td>
<td>0.41</td>
<td>0.68</td>
<td>0.55</td>
<td>0.54</td>
<td>0.47</td>
<td>0.64</td>
<td>0.58</td>
<td>0.80</td>
<td>0.54</td>
<td>1 improved, 7 reduced (-6)</td>
</tr>
</tbody>
</table>
A closer look at the satellite and in-situ snow data

Forcing data
- P, T PTHBV-grid (4x4 km²)
- Elevation EU-DEM, 25x25 m²

Snow data
- SMHI snowdepth stations (point, daily)

Hydropower companies:
- SWE point data (bi-weekly)
- Snow courses (once per year)

Satellitdata (CryoLand, HSAF, etc)
- Fractional snow cover 1x1 km²
- Snow water equivalent 25x25 km²
How to combine model and in-situ data information for assimilation of the passive microwave satellite observation?

Radiation emission model
Ex from Pullianen and Hallikainen (2001)

Satellite observed radiation:
- Radiation from atmosphere
- Radiation from ground (soil, snow, vegetation)

Spatial distribution of snow
(from model or from in-situ data)

Saturation of MW emission from snow depths larger than some threshold (150-200 mm)
On-going work:
Combined assimilation of in-situ snow data, passive microwave radiance data and spatially distributed snow models

- Forward radiation emission modelling taking snow distribution and snow properties into account
- Model necessary surface properties in the models
- Integration of ground based observations (snow, runoff, water levels, etc)

- Evaluation of impact on stream flow simulations and seasonal hydrological forecasts

Preliminary resultat:
Modelled GlobSnow SWE by taking snow distribution into account.
Conclusions

- Spatially distributed in-situ snow data do improve seasonal runoff forecasts

- Systematic biases in satellite passive microwave snow data
  - especially in the areas of interest from hydropower point of view
  - areas with high mean SWE and large spatial variability

- Outlook for using satellite based SWE data::
  - Combine information on snow distribution and snow properties from models and in-situ data in forward radiation emission modelling.
Thank you!
## Test basins:

<table>
<thead>
<tr>
<th>River basin</th>
<th>Stream flow Station/Code</th>
<th>Code</th>
<th>Lat</th>
<th>Lon</th>
<th>Area (km²)</th>
<th>Elev, mean (m)</th>
<th>Elev, std (m)</th>
<th>Forest (%)</th>
<th>Lake (%)</th>
<th>Description</th>
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<tbody>
<tr>
<td>Tornionjoki</td>
<td>Övre Abiskojokk</td>
<td>A</td>
<td>68.3</td>
<td>18.5</td>
<td>565.1</td>
<td>953.4</td>
<td>261.2</td>
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<td>North, mountain, alpine</td>
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<tr>
<td>Tornionjoki</td>
<td>Mertajärvi</td>
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<td>Tängvattnet</td>
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<td>718.1</td>
<td>167.0</td>
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<td>Medstugan nedre</td>
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<td>654.7</td>
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<td>Ryggesbo</td>
<td>E</td>
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<td>15.7</td>
<td>148.9</td>
<td>303.3</td>
<td>71.6</td>
<td>83.4</td>
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<td>Central, inland forest</td>
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<td>Testeboån</td>
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<td>61.0</td>
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<tr>
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<td>Ersbo</td>
<td>G</td>
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<td>732.0</td>
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<td>Central-west, mountain, forest</td>
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<td>Norrström</td>
<td>Vattholma</td>
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<tr>
<td>Söderköpings ån</td>
<td>Ryttarbacken</td>
<td>I</td>
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<td>7.3</td>
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<td>35.2</td>
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