

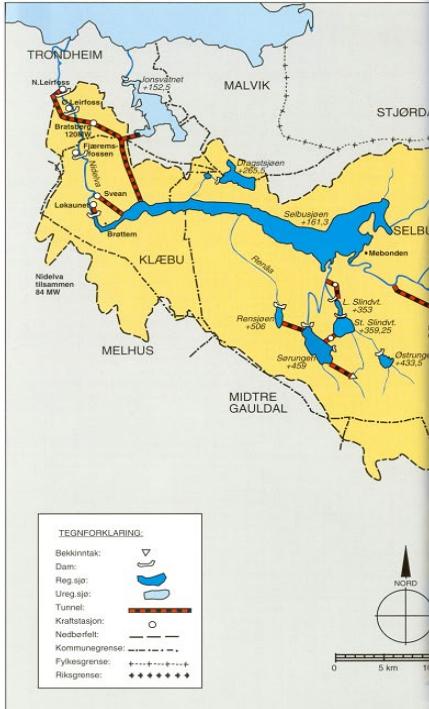
Hur kan vi öka korttidsprognosernas precision?

For optimalisering av vannkraft
produksjon



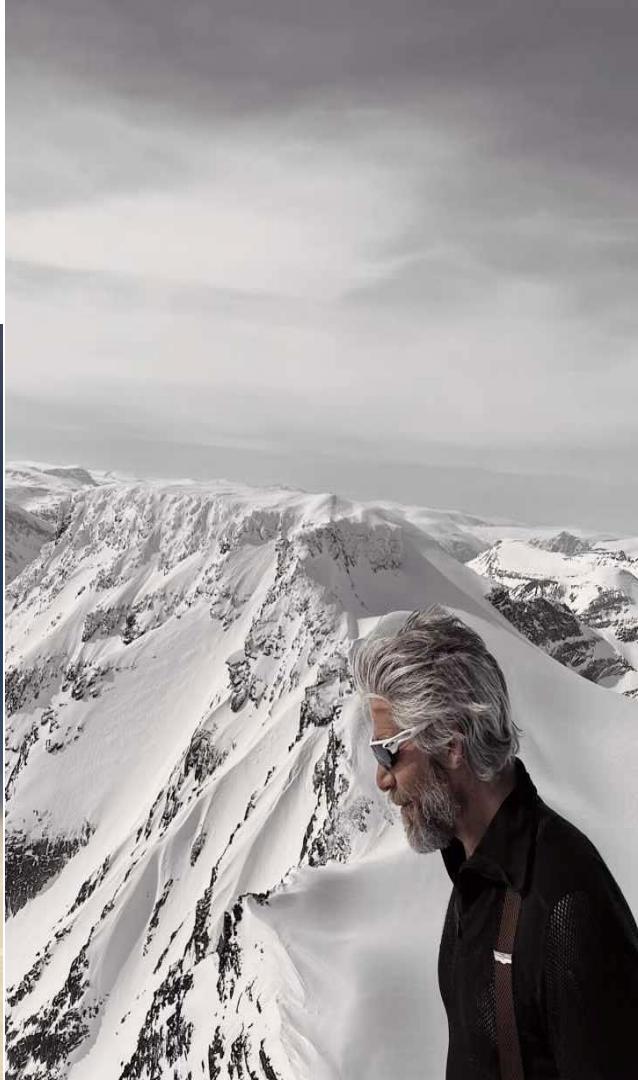


Utfordringane



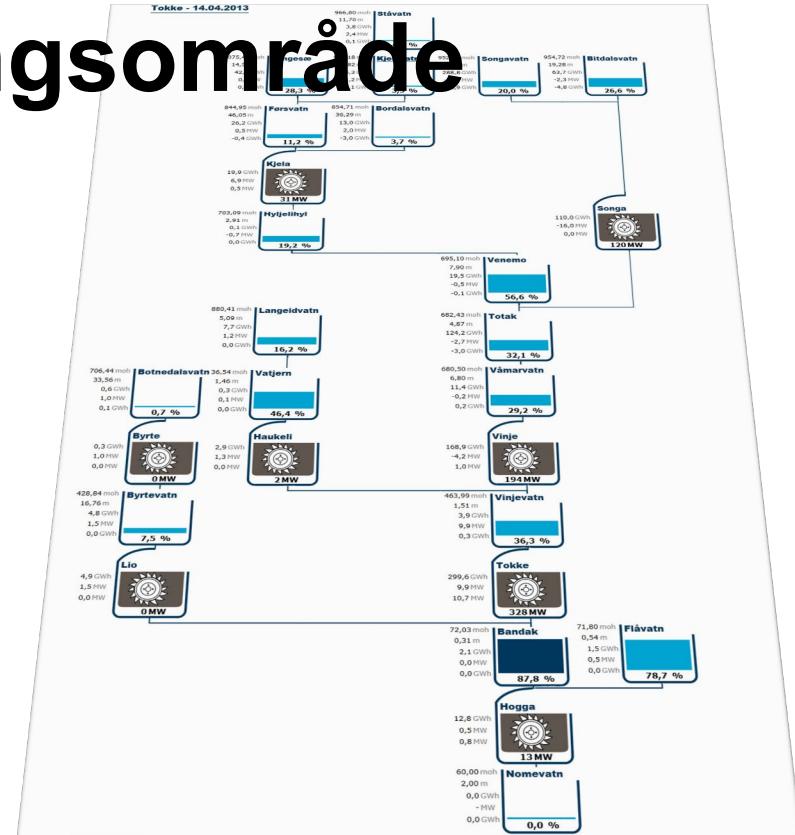
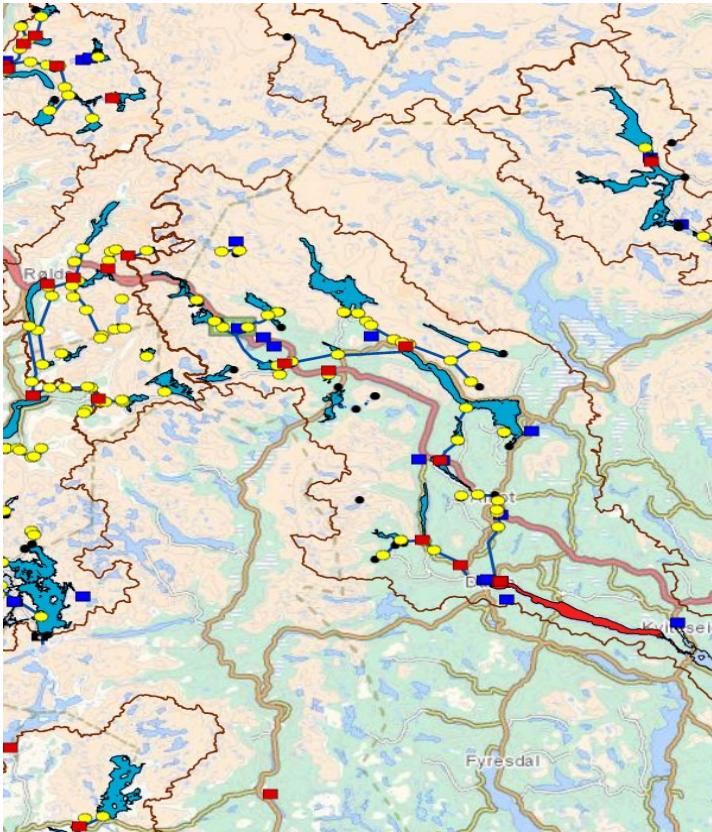
Kven og kva er....

Oddbjørn Bruland



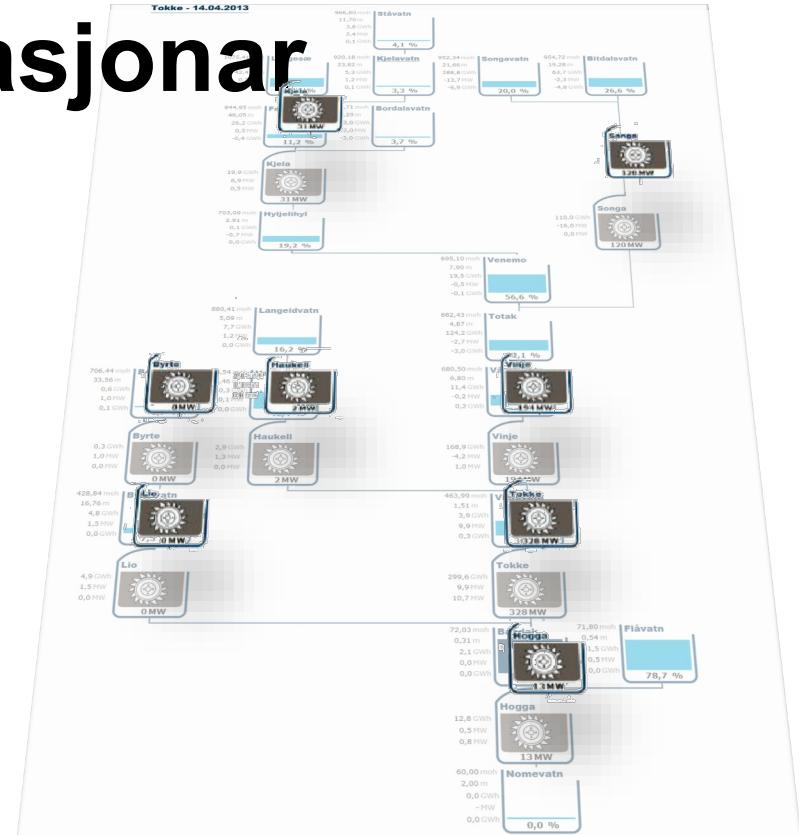
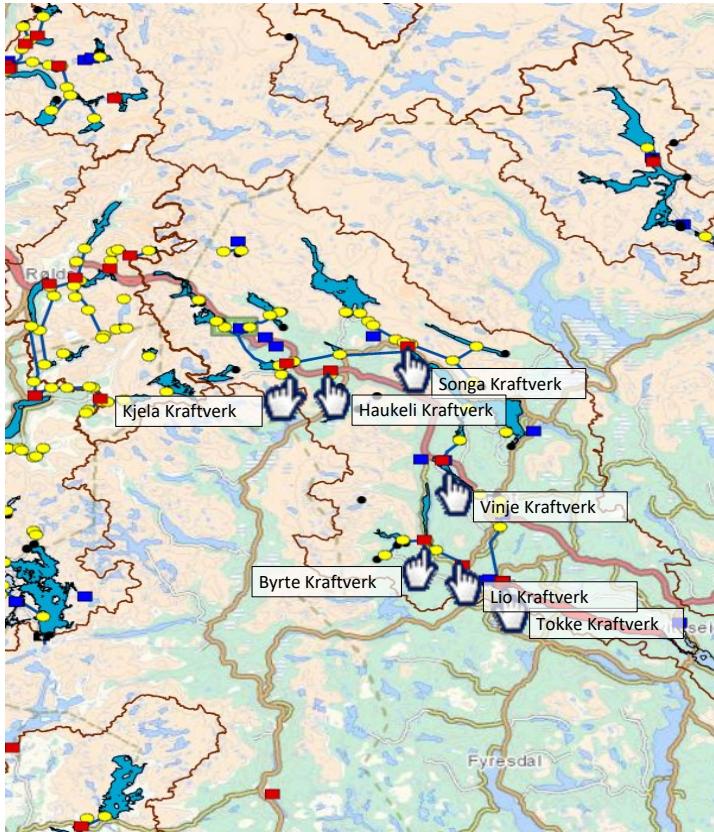


Tokke reguleringsområde

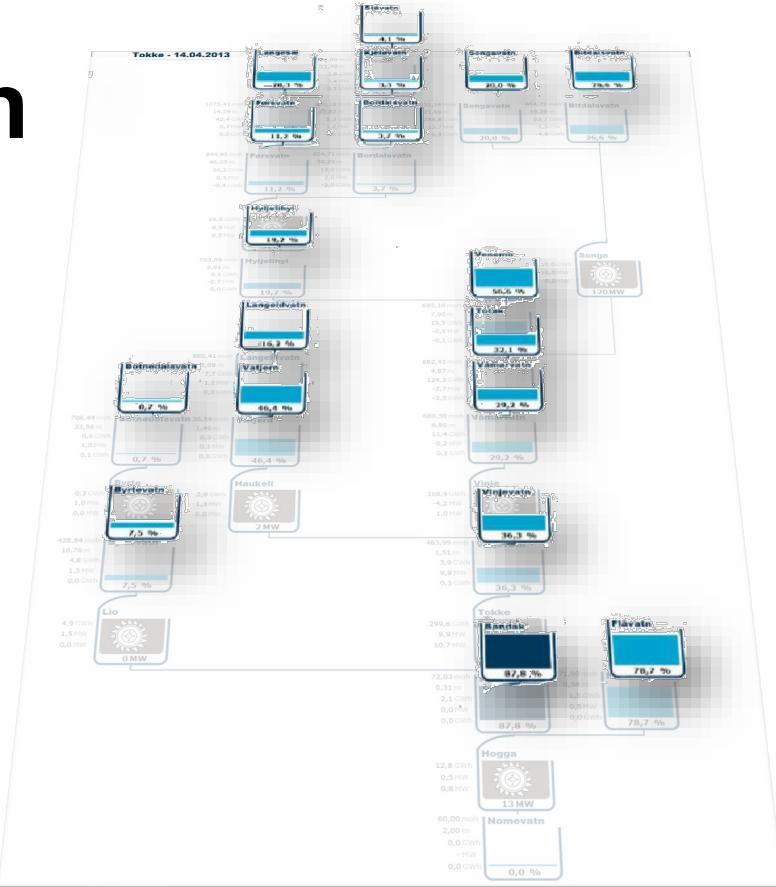
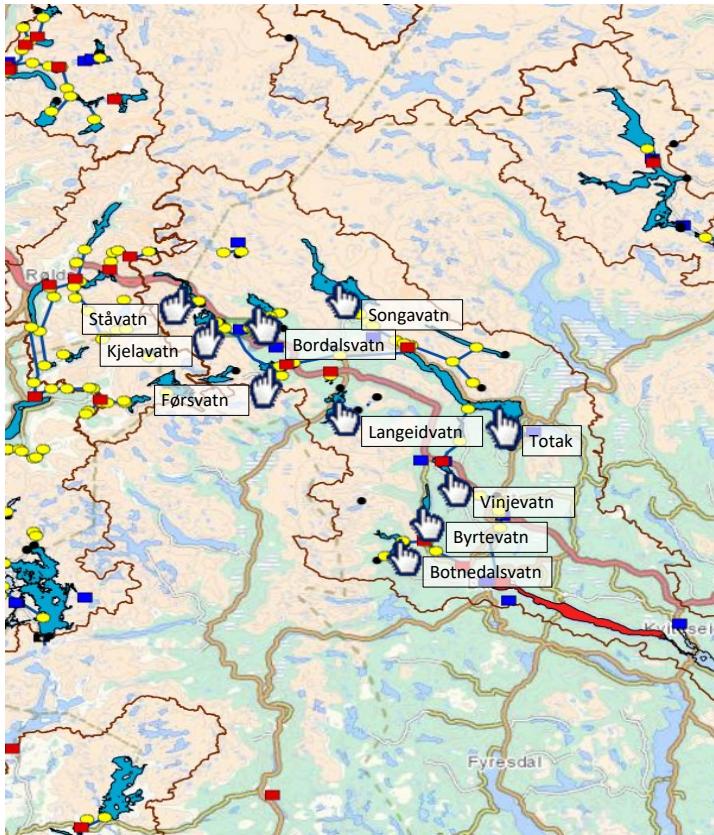




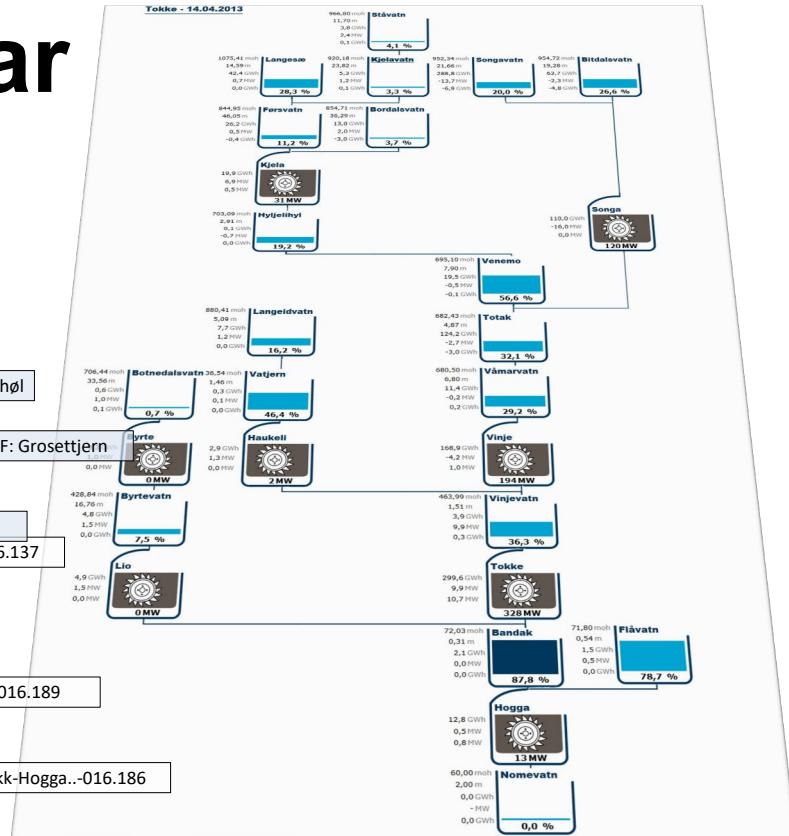
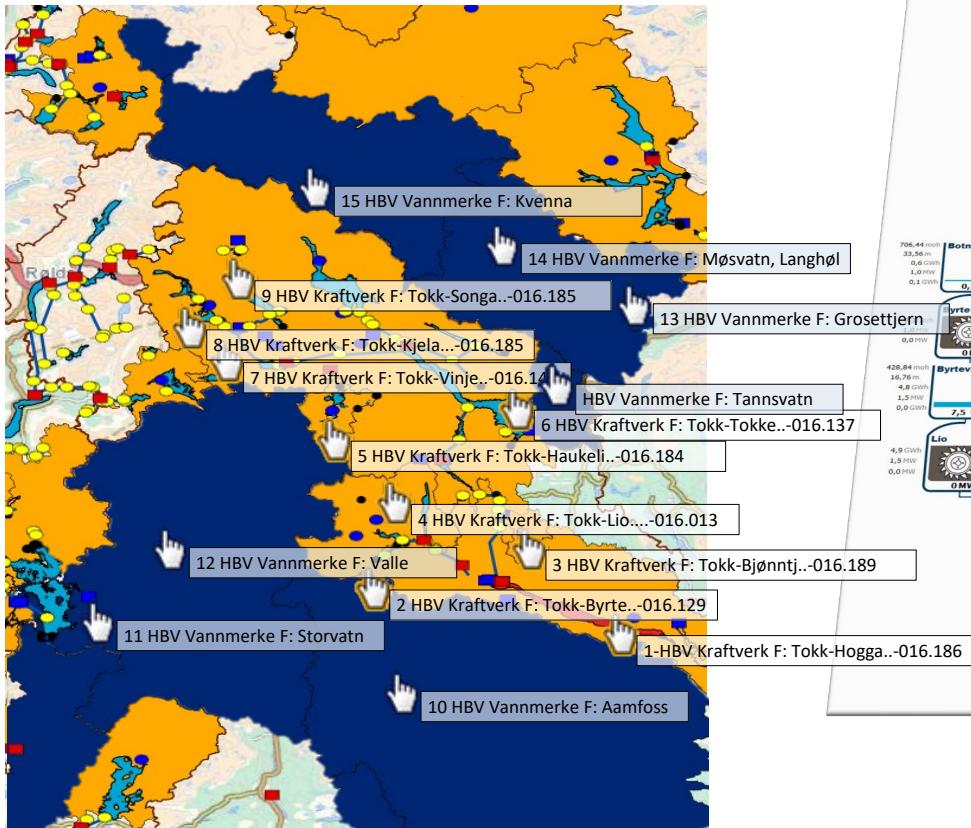
Tokke - Kraftstasjonar



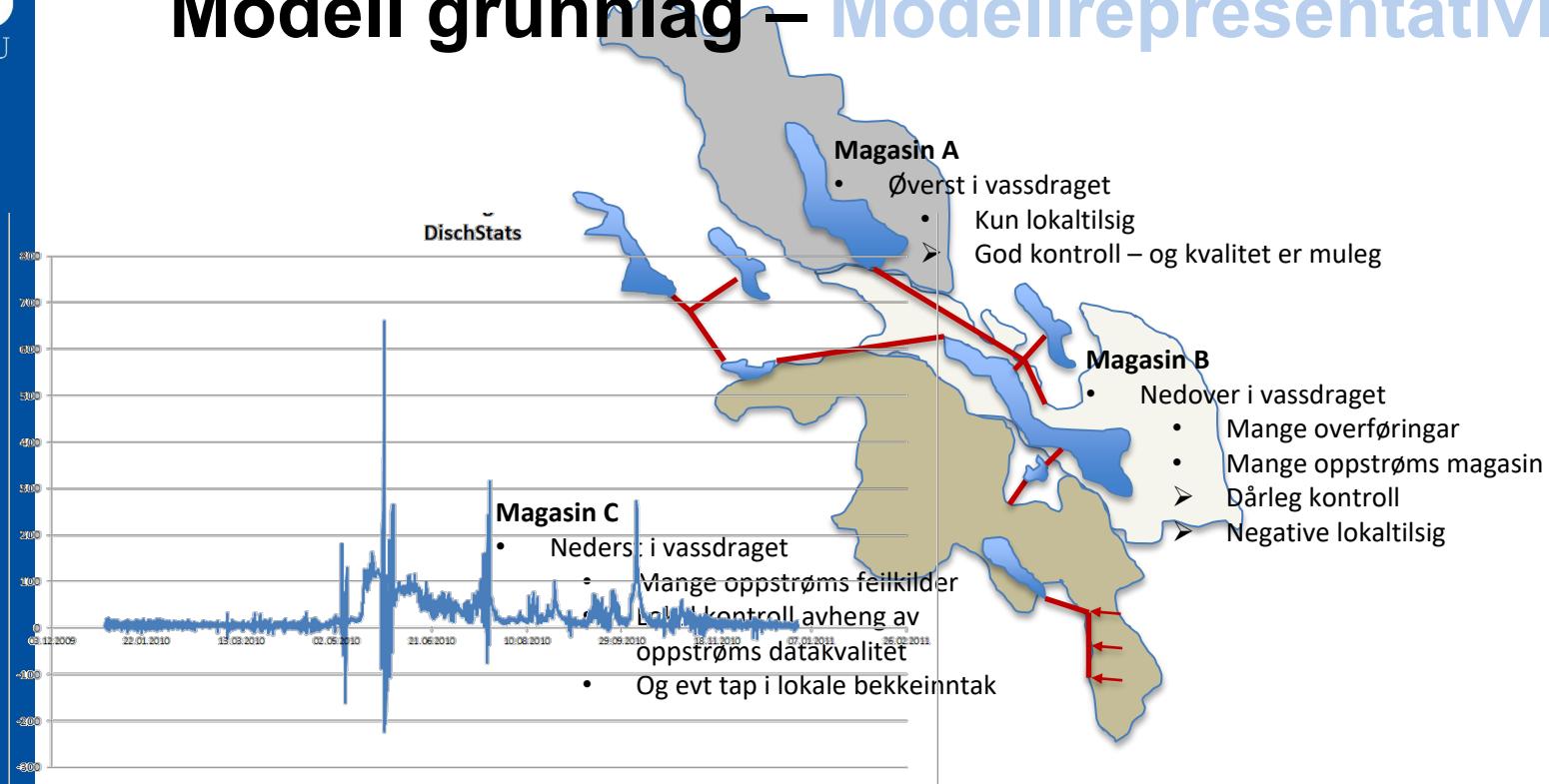
Tokke - magasin



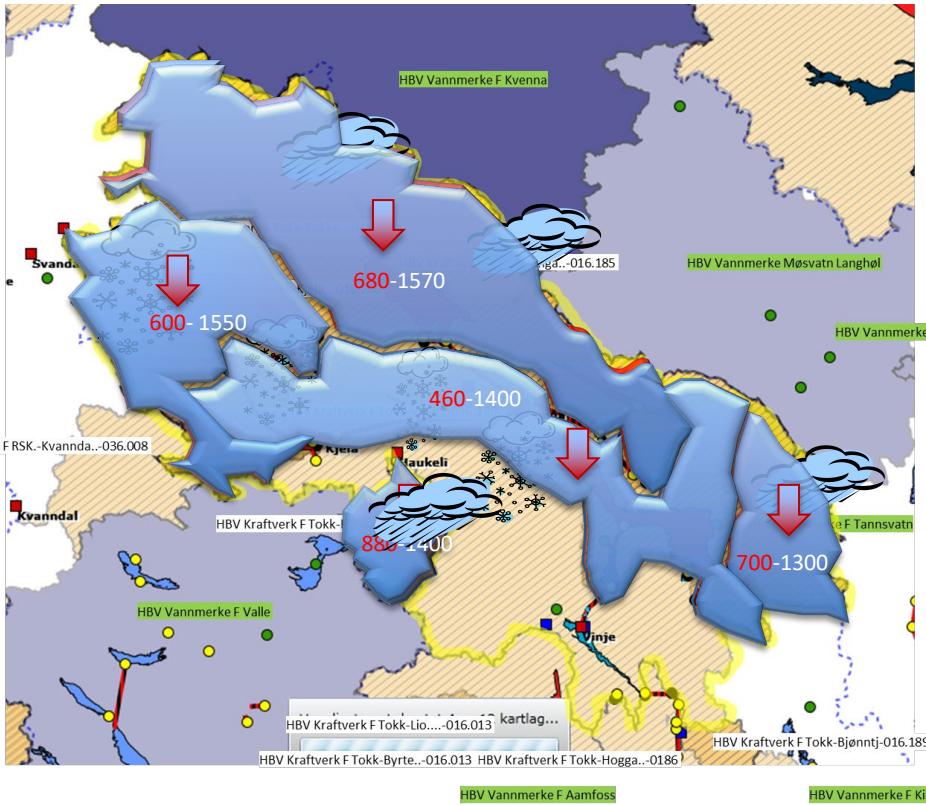
Tokke – Modellar



Modell grunnlag – Modellrepresentativitet



Konsistens i rom og tid



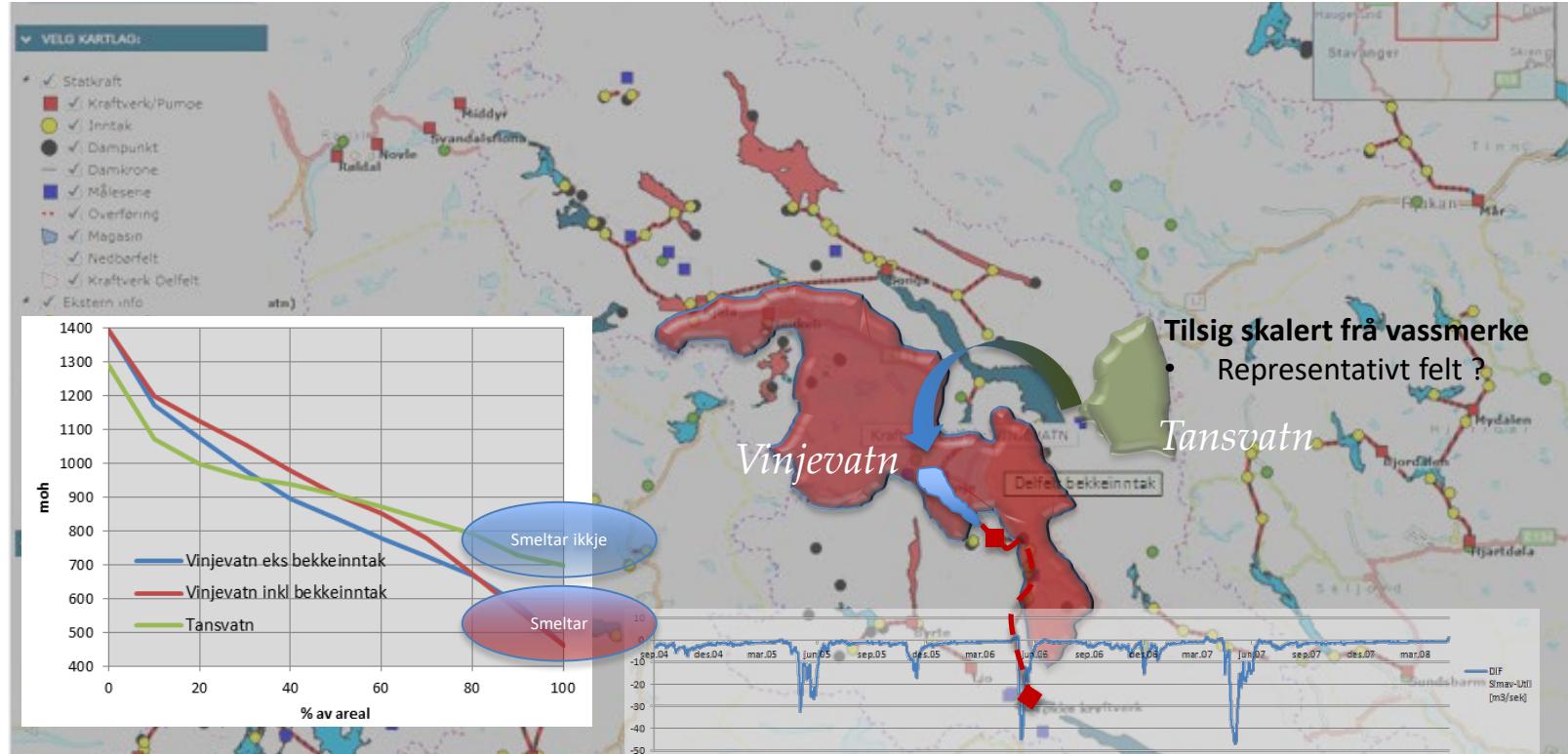
Temp og Nedb Grad: individuelt kalibrert
Regn/Snø omslag: T_x from -2.0 to 2.0°C
Smelte terskel: T_s from -1.5 to 1.5°C

Vær varsel: $T = -0.5 - 0.5^{\circ}\text{C}$, $P = 10 - 20 \text{ mm}$

Kva kan skje ???



Modell grunnlag – Modellrepresentativitet

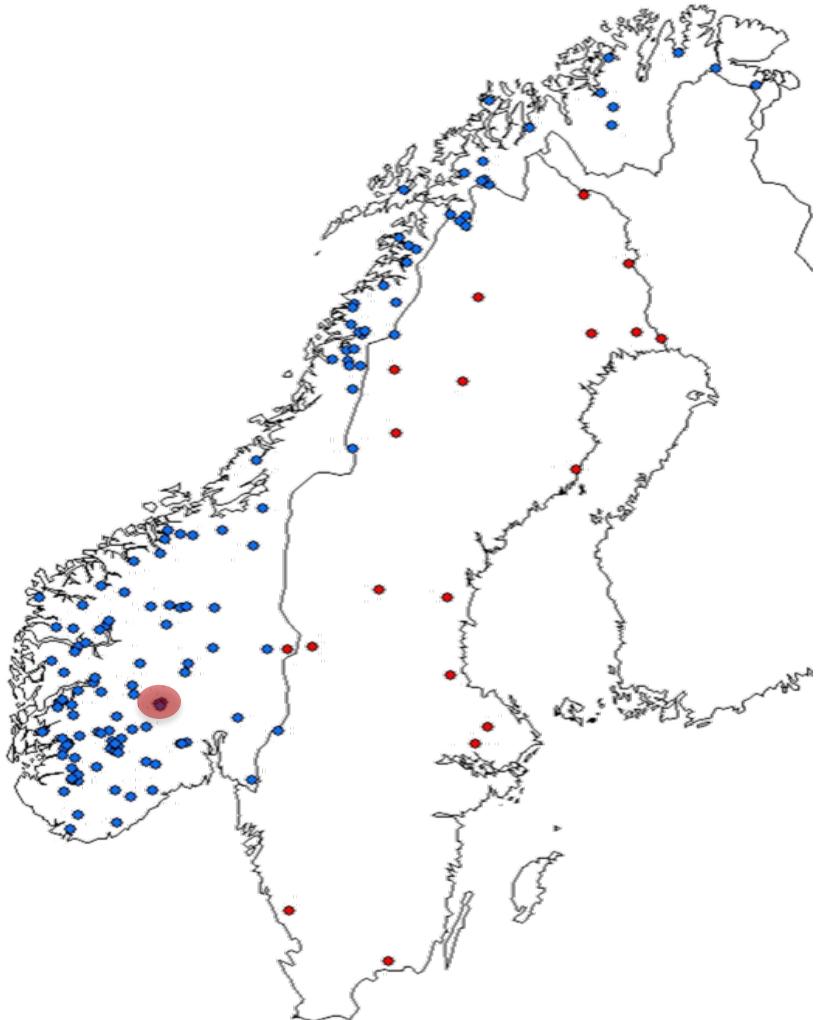




Tokke – 15 modellar av over 200
=> Stort potensiale for forbetring

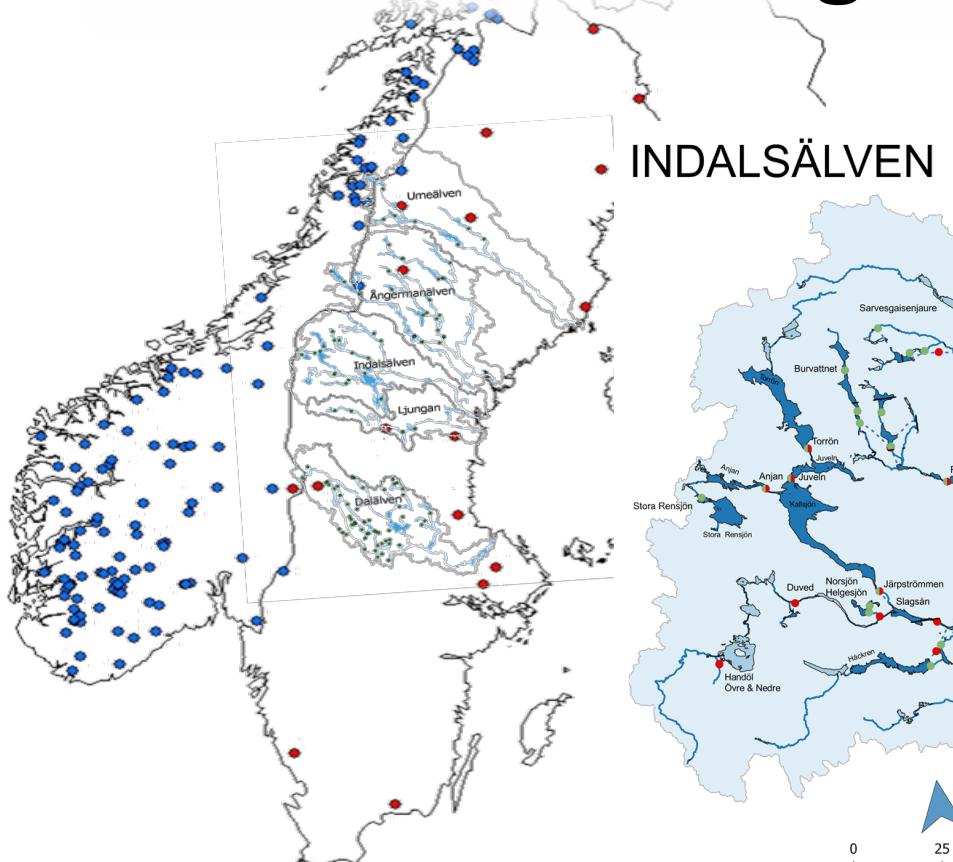


- Omfang og kompleksitet
- Modell grunnlag – Modellrepresentativitet
- Konsistens i rom og tid
- Oppdatering
- Bruk av tilgjengeleg informasjon
- Formidling – intern dialog

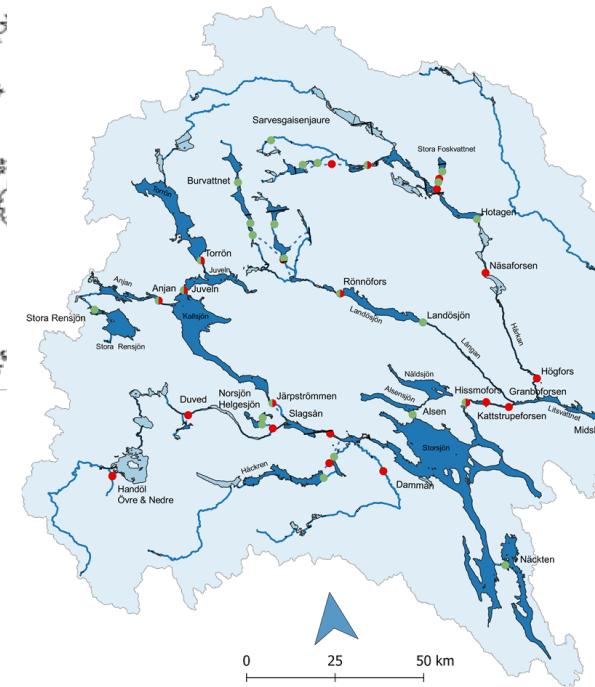




Hvilke utfordringar har Sverige?



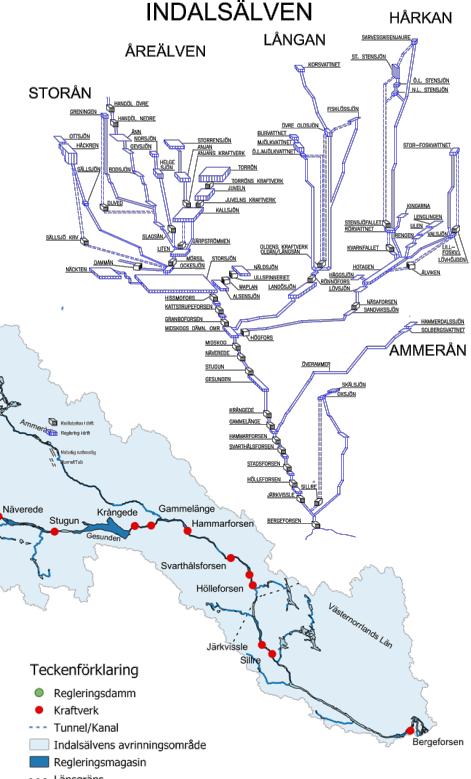
• INDALSÄLVEN



SCHEMATISK BILD
AV
INDALSÄLVEN

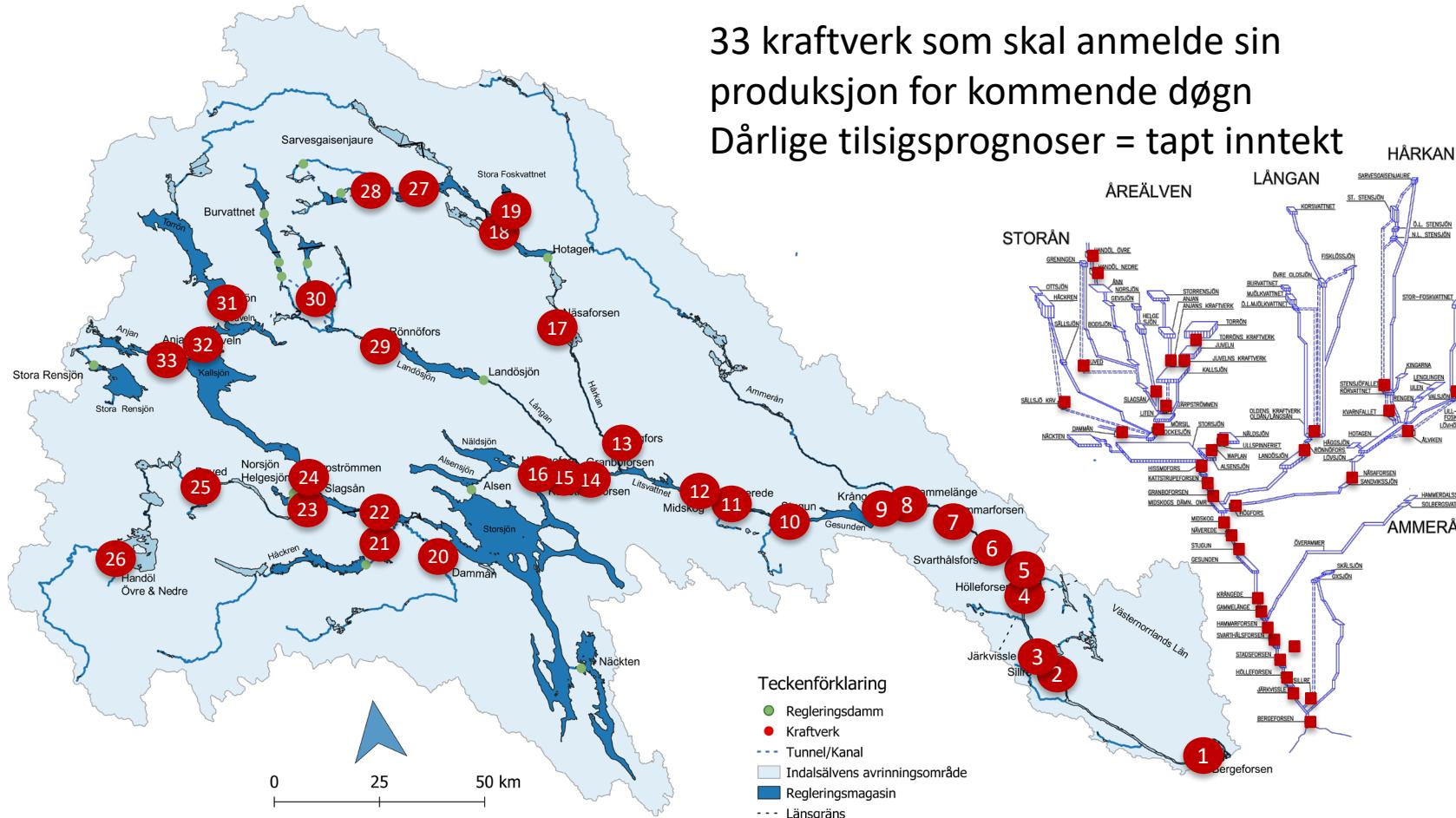
ÄREÄLVEN LÄNGAN

STORÄN



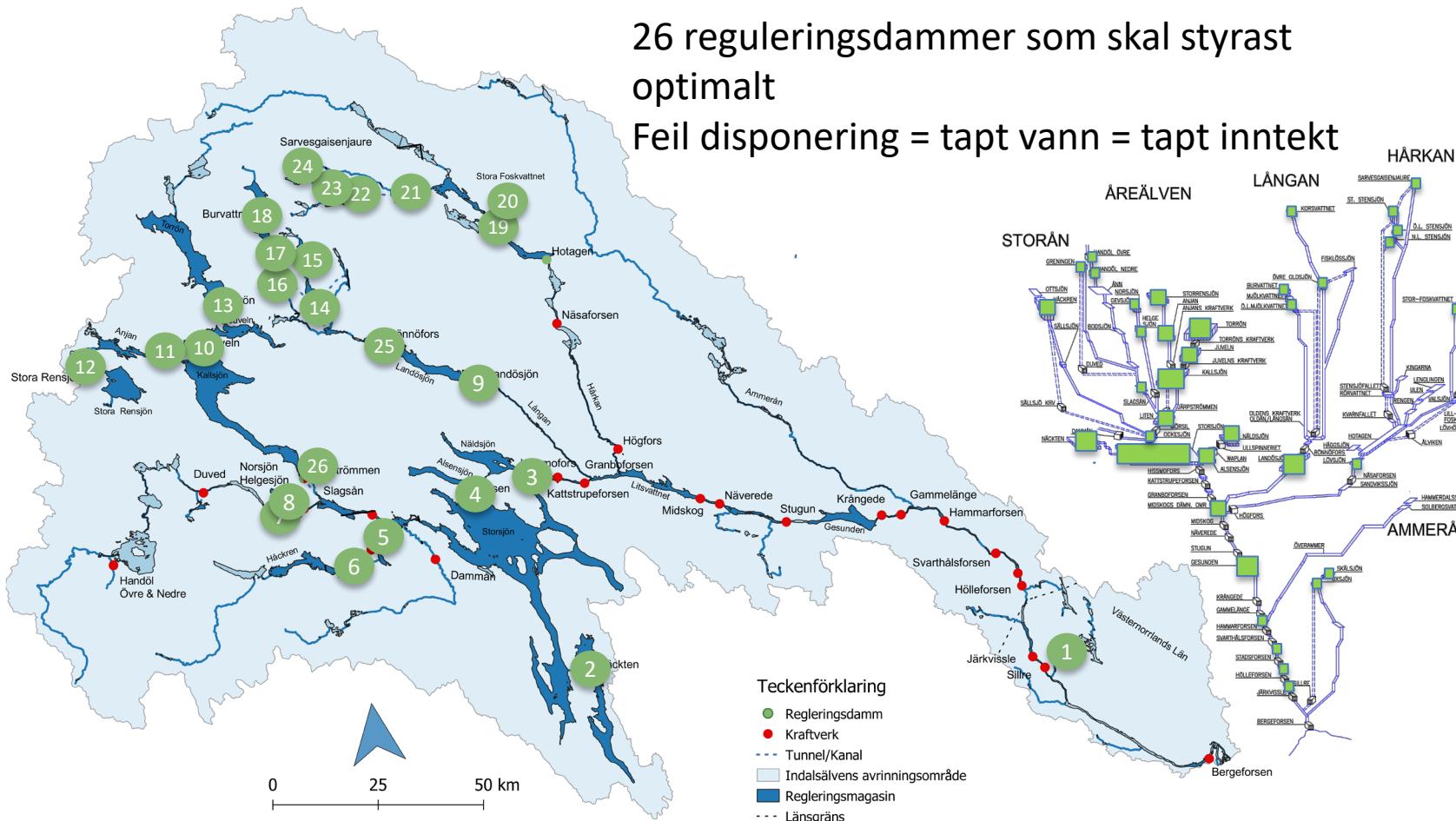


INDALSÄLVEN



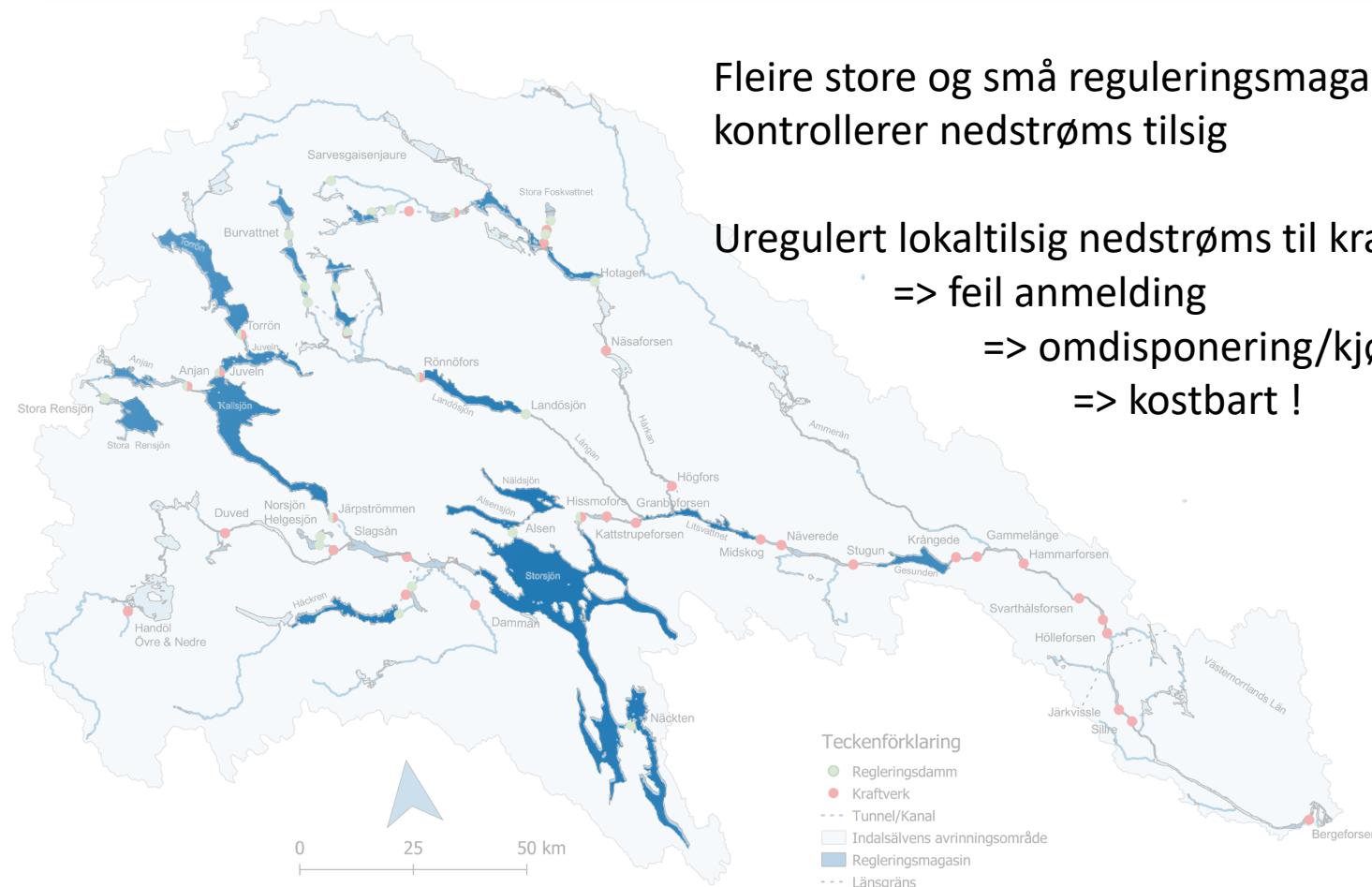


INDALSÄLVEN



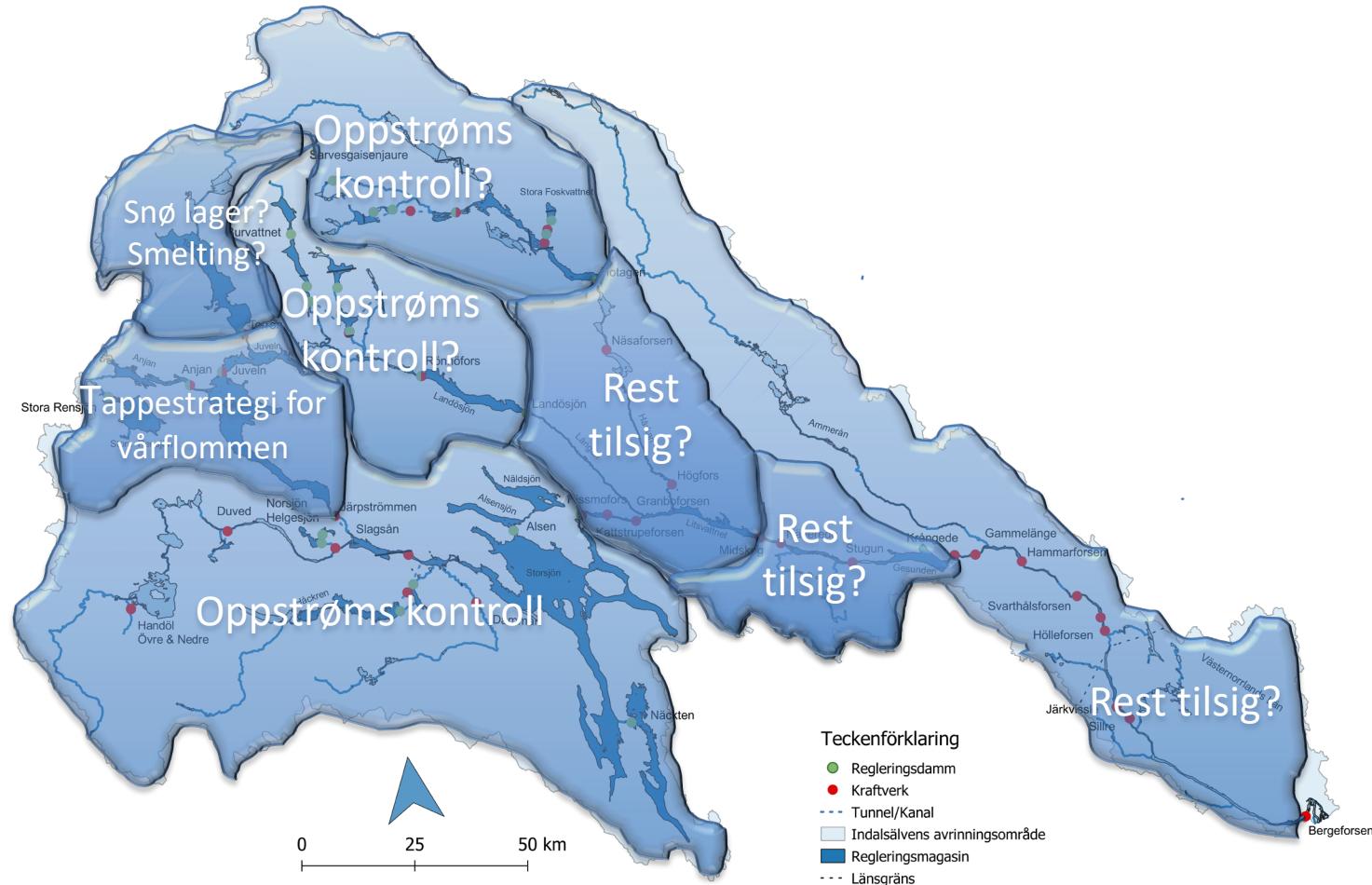


INDALSÄLVEN

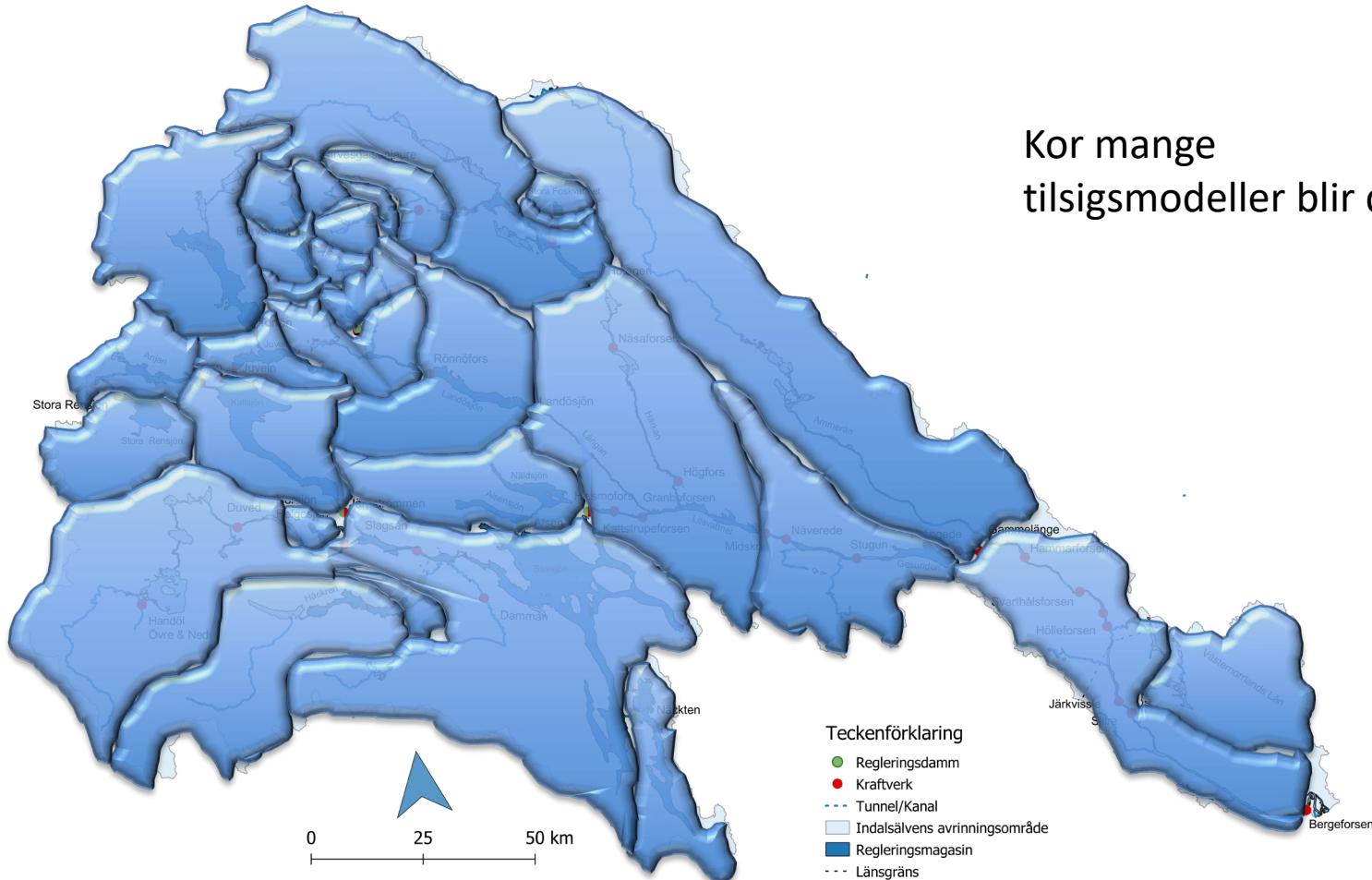




INDALSÄLVEN



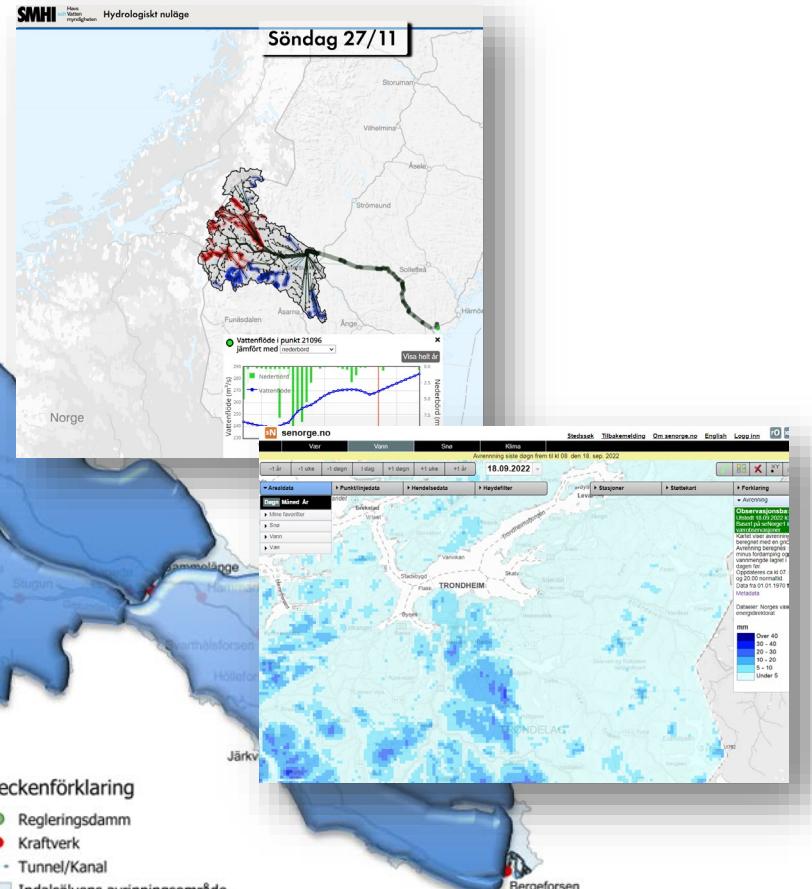
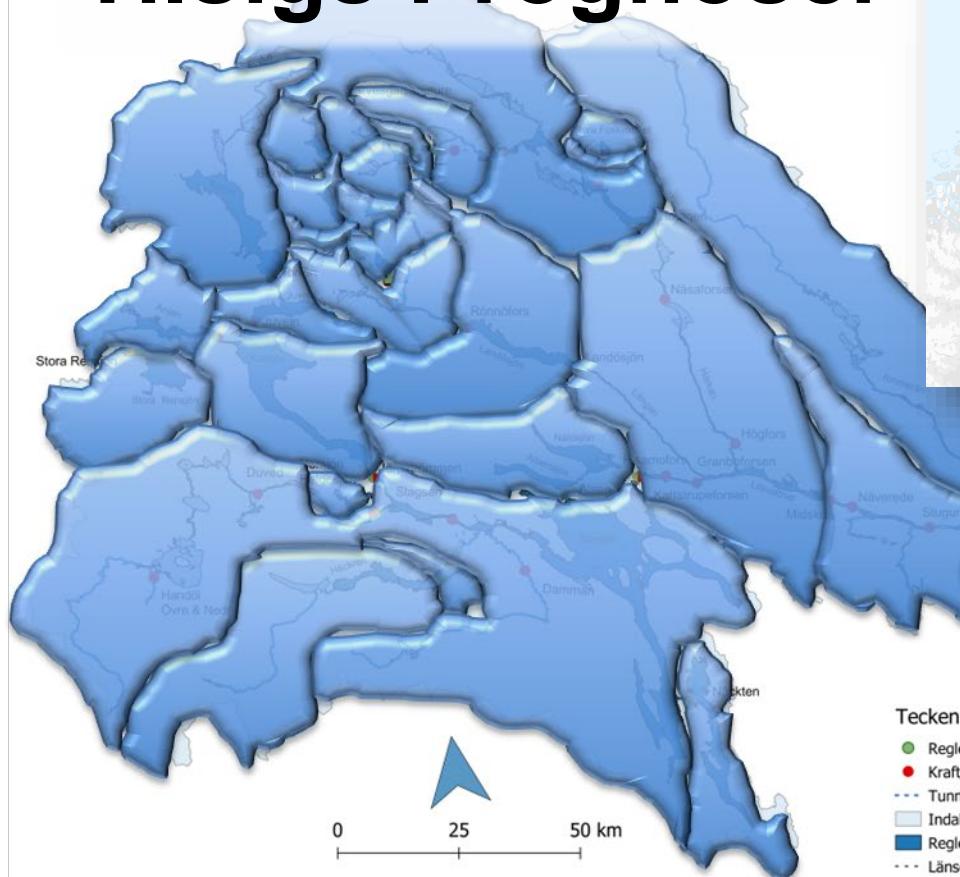
INDALSÄLVEN



Kor mange tilsigsmodeller blir det?



Tilsigs Prognoser

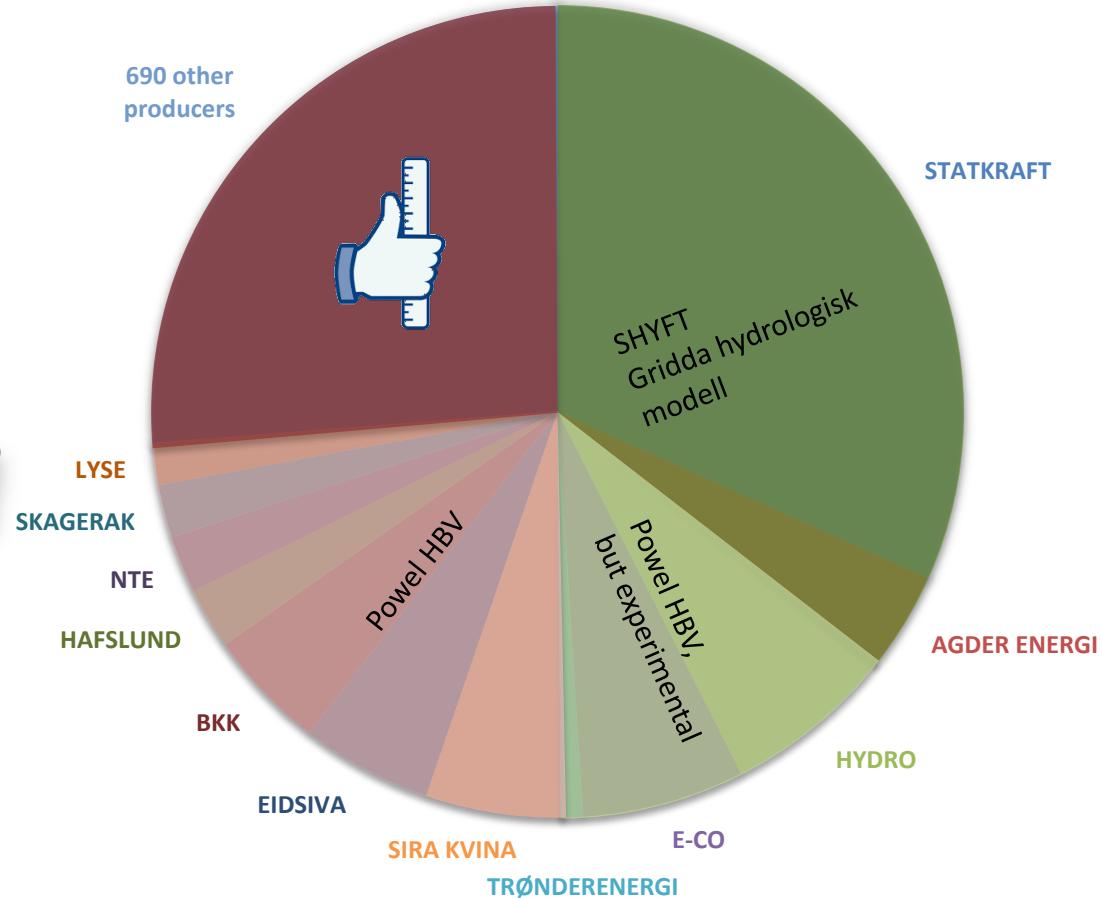


Teckenförklaring

- Regleringsdamm
- Kraftwerk
- - - Tunnel/Kanal
- Indalsälvens avrinningsområde
- Regleringsmagasin
- - - Länsgräns



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Snart kan kunstig intelligens styre vannkraftverk

Agder Energi og Universitetet i Agder vil at datamaskiner selv skal lære seg å styre kraftproduksjonen. Får de det til blir de først i verden.

Av [Walter Norman Wehus](#)



Å planlegge bruk av vannreservoarer er en uhøy kompleks operasjon. Nå vil forskere at datamaskiner selv skal lage modellene ved å prøve og feile. Bildet er fra Vatnedalsdammen. [Foto: Agder Energi]



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Statkraft

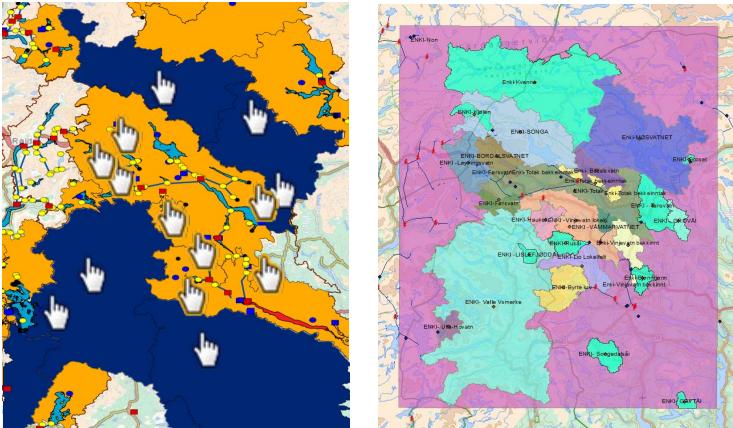


StakraftHYdrologicalForecastingTool

SHYFT

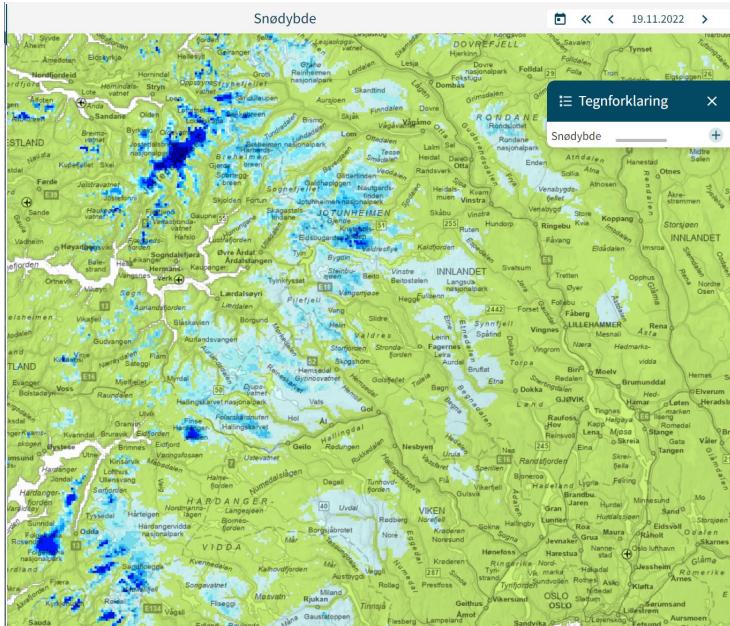


Hvorfor gridda modell?



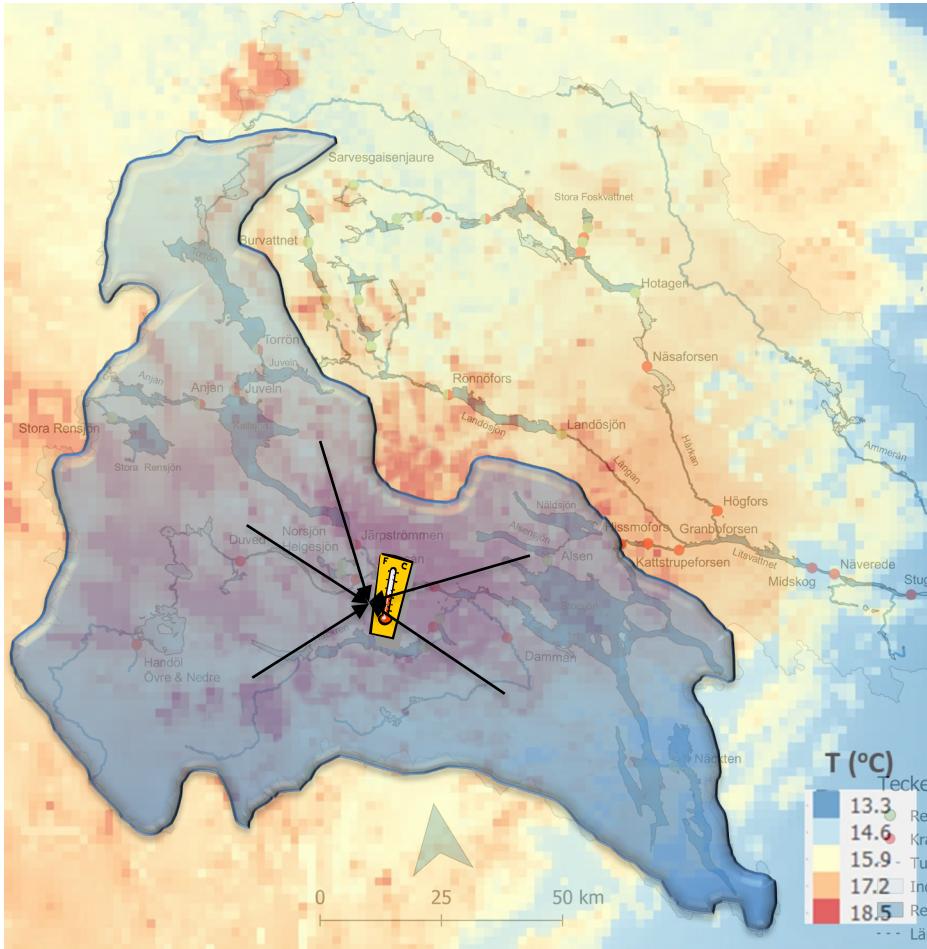
- Ein modell pr vassdrag
 - Redusere antal modeller og få enklare vedlikehald
 - Bedre konsistens mellom delfelt
 - Bedre representativitet – prognose på alle delfelt og inntak

Hvorfor gridda model?



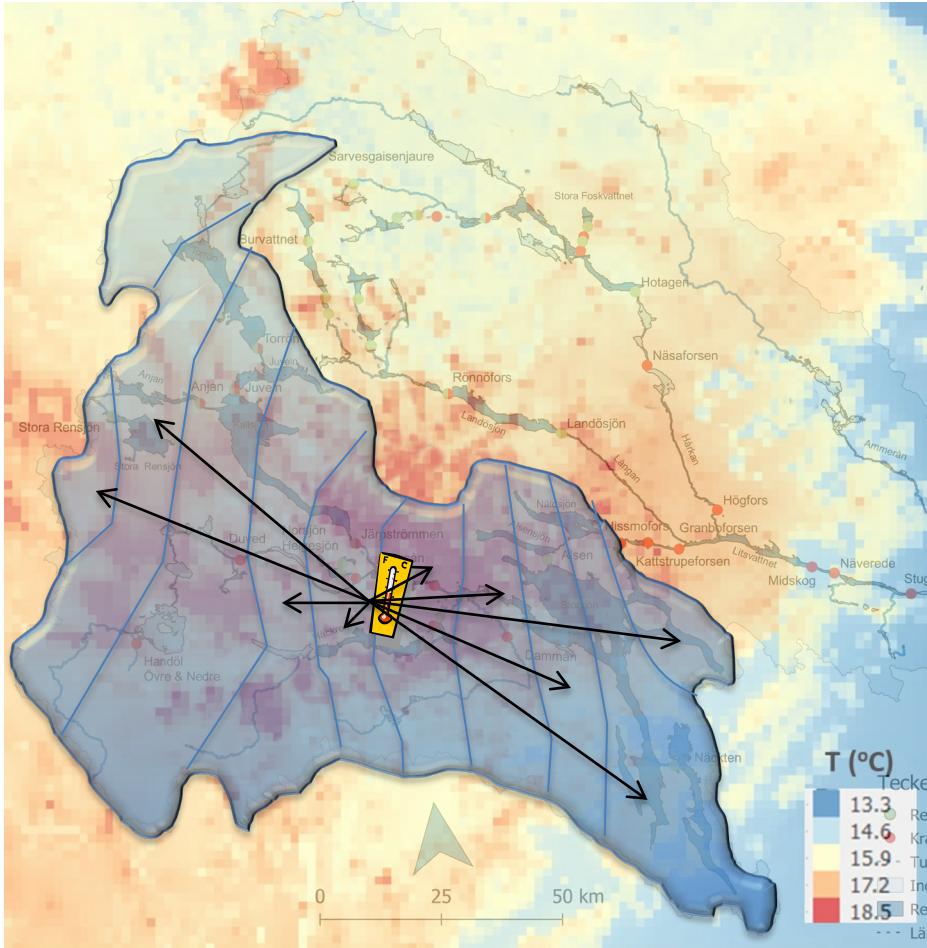
- Oppdatering av snømagasin
 - Direkte samanliknbart med satellittbilde
 - Og med snømålingar – egna for bruk av terrengkorrelasjon i radarmålte data

INDALSÄLVEN



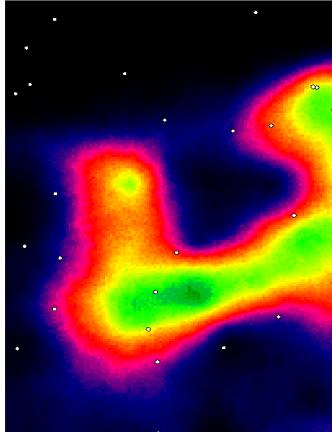
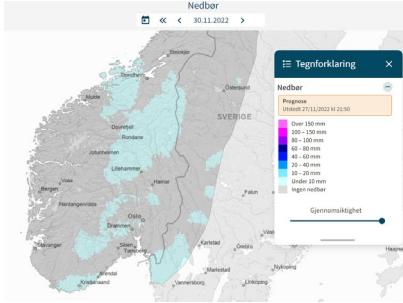
Frå detaljert informasjon frå met prognose (nedb og temp)
⇒ Middeltemp i tyngdepunkt i HBV felt
⇒ Taper viktig informasjon

INDALSÄLVEN



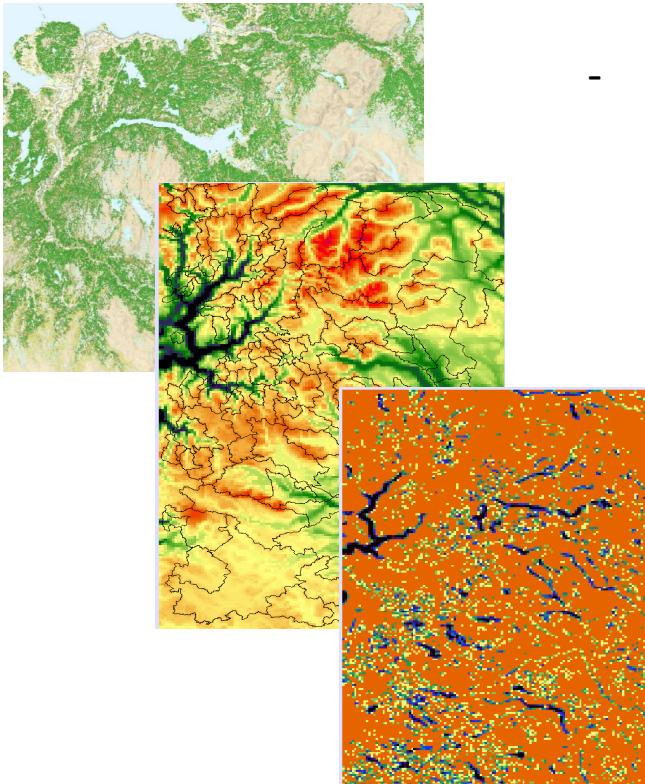
Frå tyngdepunkt felt til kvar høgdesone med kalibrert gradient for temperatur og nedbør
⇒ Introduserer nye feil og høgare usikkerheit
⇒ Kor mykje informasjon er tapt?
⇒ Kor mange feilkilder er introdusert?

Hvorfor gridda model?



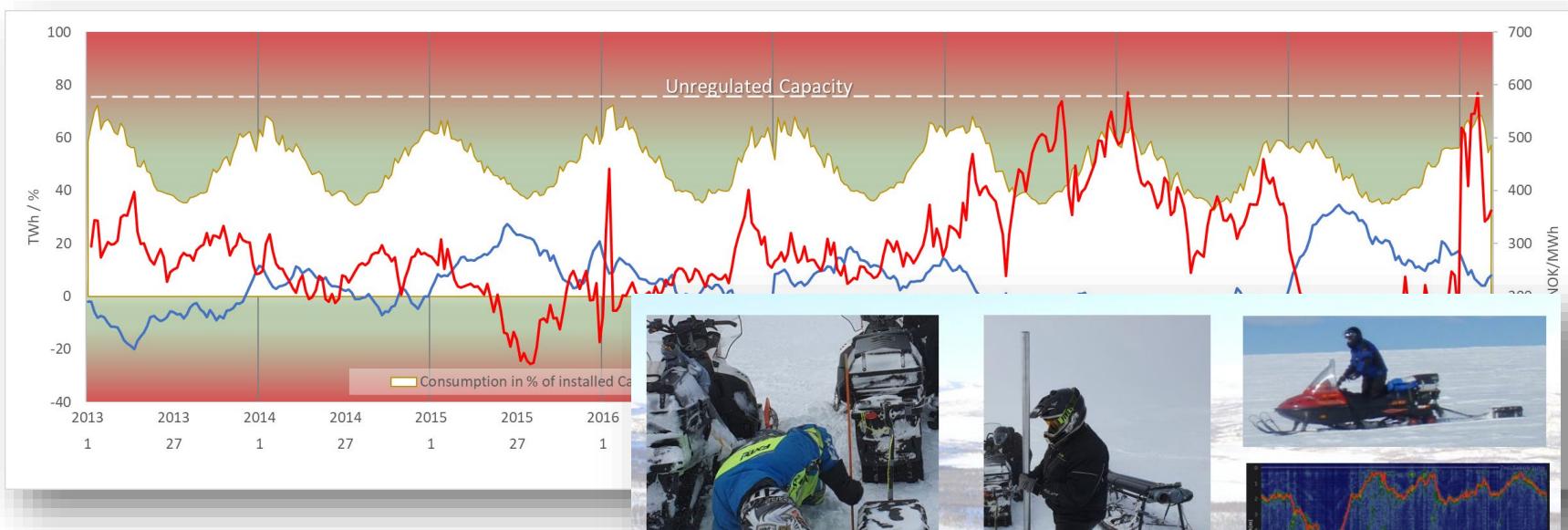
- Bedre utnyttelse av værprognoser
 - Enkel bruk av gridda nedbør, temperatur data og andre produkt frå met.no
 - Arome data på $2,5 \times 2,5 \text{ km}^2$
- Meir sofistikerte metoder for interpolering av observerte verdiar
 - Alt frå enkle til kompliserte statistiske metodar

Hvorfor gridda modell?



- Direkte kobling til GIS data
 - Terrengmodell
 - Vegetasjon
 - Vannvegar, Innsjøar
 - Bredekning
 - mm

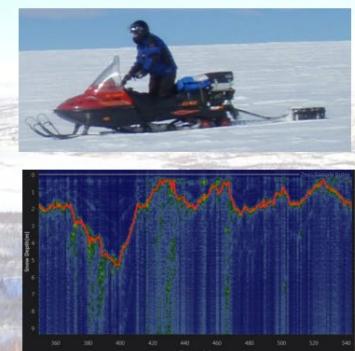
Og snøen er spesielt viktig



Probing for snow depth

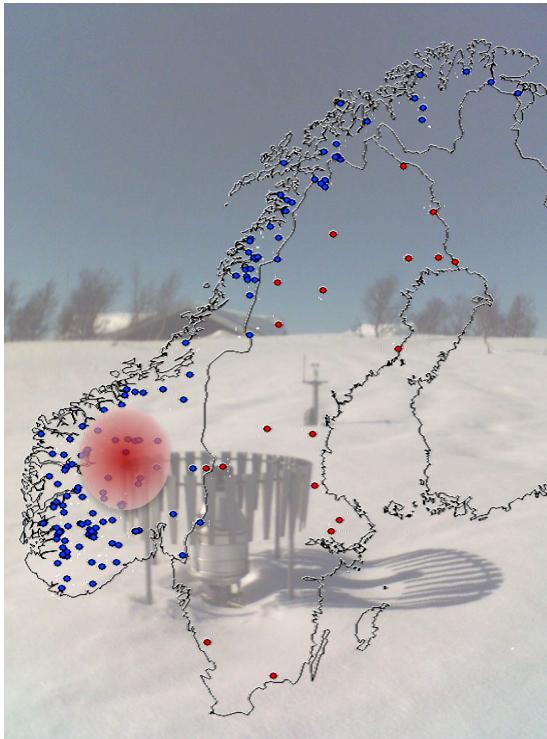


Snow density measurements



Continuous snow radar observations

Kor viktig?



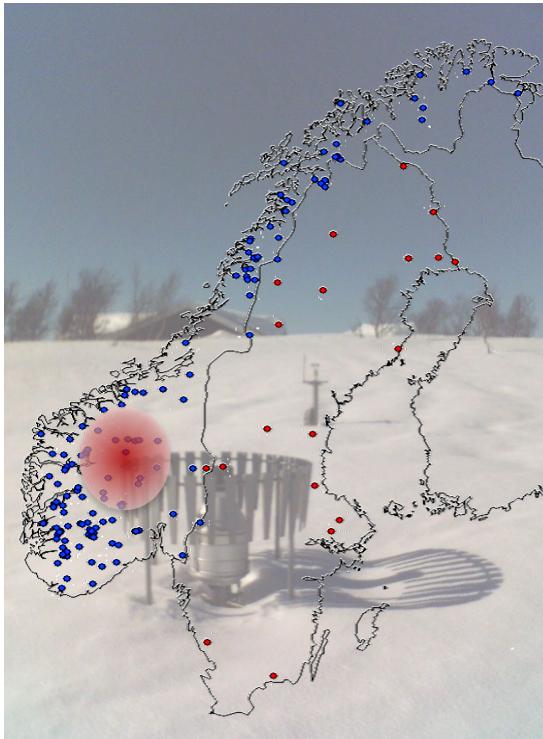
In 2008 -

One high altitude **precipitation station**



Statkraft

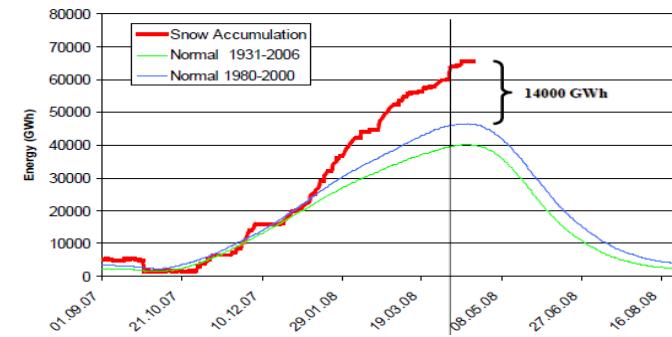
.... eit eksempel...



In 2008 -

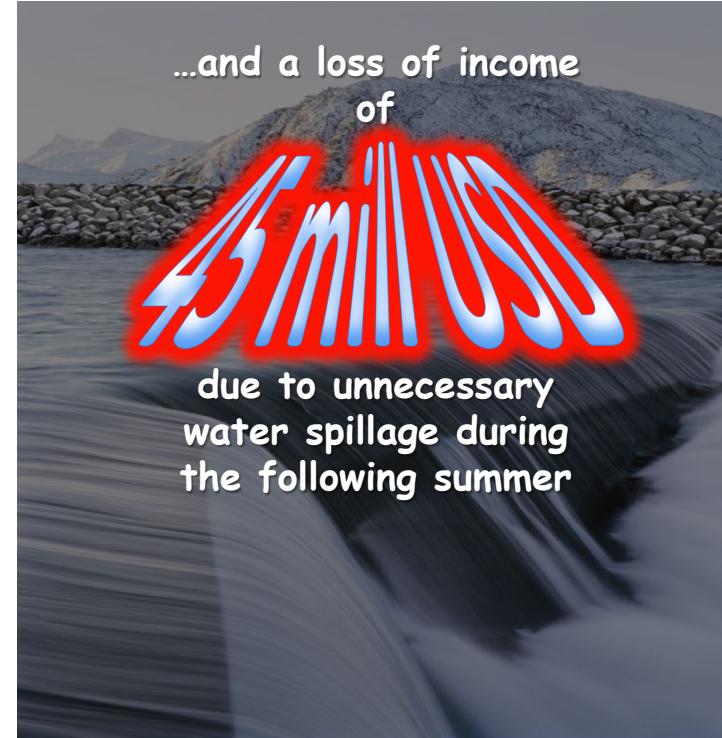
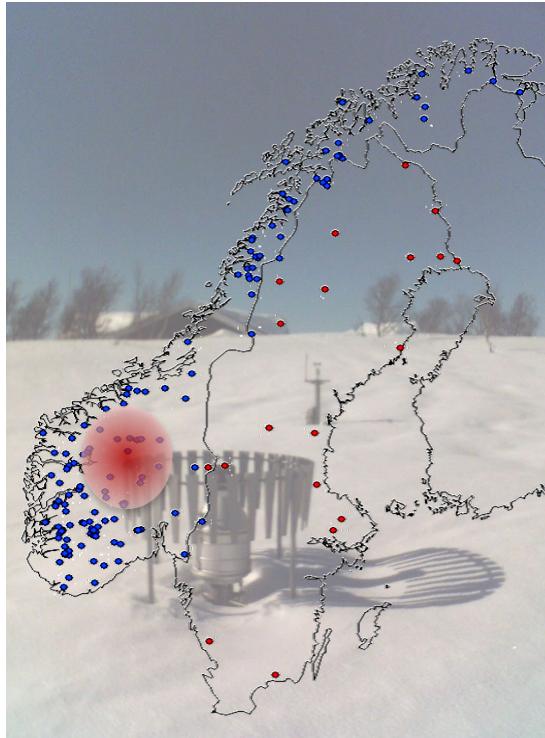
One high altitude precipitation station

... with an instrumental
error...





...på verdien av god informasjon....



Snøen er spesielt viktig

- Auker med høgde
- Smelter i solhelling
- Blir omfordelt med vind
- Samler seg i depresjonar

<= GIS



UPPSALA
UNIVERSITET

The SNODDAS project



Tomorrow's forecast for snow water equivalents -
preliminary results of an updated toolbox for
mountain catchments

...tar man steget fullt ut?

Akkumulasjonsfasen



Tidleg snødekkje
100% dekke
⇒ Haustflaumar
Kontroll ???

Maks akkumulasjon



Snømålingar
Re-distribusjon modellert
Kontroll ?
Snoddas mmfl prosjekt

I avsmeltnings fasen



Delvis snødekt
Kor er snøen
Kor mykje er igjen
Oppdatering
Kontroll ?????

...tar man steget fullt ut?

Rett snø smelting viktig

Akkumulasjonsfasen



I avsmeltnings fasen



...tar man steget fullt ut?

I avsmeltnings fasen



Snøfordeling – avgjeraende for smelteintensitet

Initiell snøfordeling $f(\text{terreng}, \text{wind}++)$ ↗
+ smelteforløp $f(\text{terreng}, \text{energibalanse}, \text{tid})$ ↘

Smelting – sekundært i forhold til kor store områder det smelter frå, men ...

$f(\text{energibalanse}, \text{terreng})$
Energibalanse f(værtype)

Akkumulasjonsfasen



Ofte full snødekning

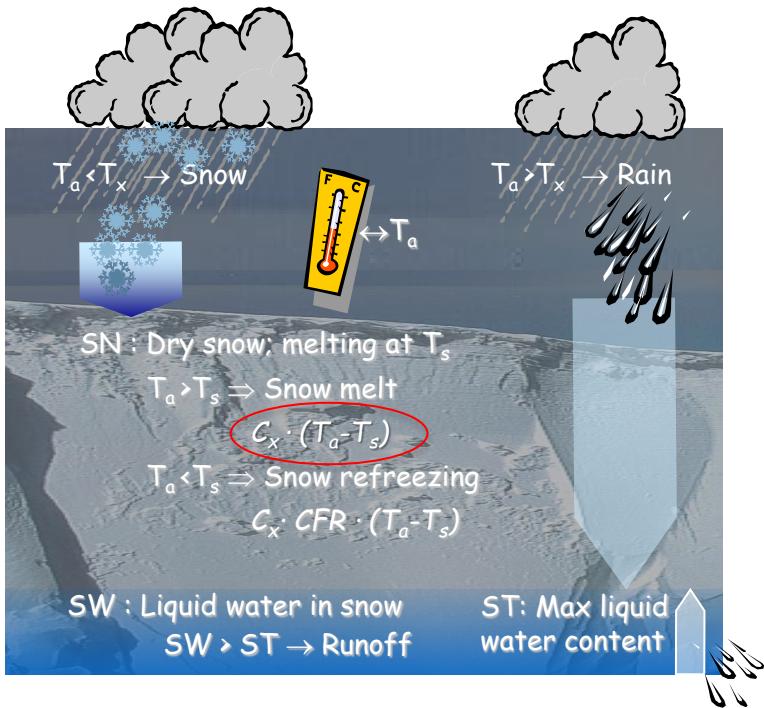
Kombinasjon snøsmelting og heftig haust regn

Smelting $f(\text{temp}, \text{luftfuktighet})$

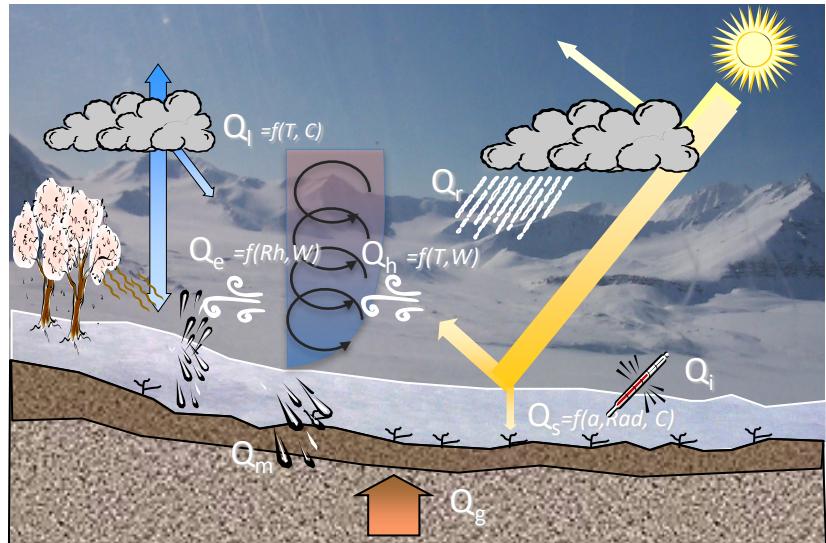
Gjennomsnittleg OK graddagsfaktor..... er sannsynlegvis for lav
dvs energibalansen er meir riktig

Blir viktigare i forhold til aukande flomfare.... I 2030, 2040, 2050, **2060...**

Graddag vs Energibalanse



$$Q_s + Q_l + Q_h + Q_e + Q_g + Q_r = Q_i + Q_m$$



Energibalanse vs Graddag

Litteratur gjennomgang

- Søk på studier som sammenlikner energibalanse og graddag og snøsmelte modellering
- 220 studier identifisert
- 86 relevante
- 5 essensielle

- Bengtsson, L. (1976). Snowmelt estimates from {Energy} budget studies. *Nordic Hydrology*, 7, 3–18.
- Bruland, O., & Killingtveit, A. (2002). An energy balance based HBV-model with application to an Arctic watershed on Svalbard, Spitsbergen. *Nordic Hydrology*, 33(2–3), 123–144. <https://doi.org/10.2166/nh.2002.0019>
- Bruland, O., Maréchal, D., Sand, J., ... Kyring, J. E. (2007). Energy and water balance studies of a snow cover during spring meltwater runoff in an Arctic site. *Theoretical and Applied Climatology*, 70(1–4), 53–63. <https://doi.org/10.1007/s00704-017-0005>
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- Brunt, D. (1952). *Physical and Dynamical Meteorology*. Cambridge University Press. https://books.google.no/books?id=RHE3eVSSomUC&dq=Physical+and+Dynamical+Meteorology&lr=&hl=no&source=gbs_navlinks_s
- Essery, R., Morin, S., Lejeune, Y., & B Ménard, C. (2013). A comparison of 1701 snow models using observations from an alpine site. *Advances in Water Resources*, 55, 131–148. <https://doi.org/10.1016/J.ADVWATRES.2012.07.013>
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- Kolberg, S. A. (2018). *Strålings-input fra geostasjonær satellitt* (2018:00187). Sintef.
- Liston, G. E., Winther, J.-G., Bruland, O., Elvehøy, H., & Sand, K. (1999). Below-surface ice melt on the coastal Antarctic ice sheet. *Journal of Glaciology*, 45, 273–285.
- Luijting, H., Vikhamar-Schuler, D., Aspelien, T., Bakketun, Å., & Homleid, M. (2018). Forcing the SURFEX/Crocus snow model with combined hourly meteorological forecasts and gridded observations in southern Norway. *Cryosphere*, 12(6), 2123–2145. <https://doi.org/10.5194/TC-12-2123-2018>
- MacKay, J. D., Barrand, N. E., Hannah, D. M., Krause, S., Jackson, C. R., Everest, J., & Áoalgeirsdóttir, G. (2018). Glacio-hydrological melt and run-off modelling: Application of

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- Bruland, O., Maréchal, D., Sand, K., & Kilingtveit, A. (2001). Energy and water balance studies of a snow cover during snowmelt period at a high arctic site. *Theoretical and Applied Climatology*, 70(1–4), 53–63. <https://doi.org/10.1007/s007040170005>
- MacKay, J. D., Barrand, N. E., Hannah, D. M., Krause, S., Jackson, C. R., Everest, J., & Aoalgeirsdóttir, G. (2018). Glacio-hydrological melt and run-off modelling: Application of a limits of acceptability framework for model comparison and selection. *Cryosphere*, 12(7), 2175–2210. <https://doi.org/10.5194/TC-12-2175-2018>
- Magnusson, J., Farinotti, D., Jonas, T., & Bavay, M. (2011). Quantitative evaluation of different hydrological modelling approaches in a partly glaciated Swiss watershed. *Hydrological Processes*, 25(13), 2071–2084. <https://doi.org/10.1002/HYP.7958>
- Meeks, J., Moeck, C., Brunner, P., & Hunkeler, D. (2017). Infiltration under snow cover: Modeling approaches and predictive uncertainty. *Journal of Hydrology*, 546, 16–27. <https://doi.org/10.1016/J.JHYDROL.2016.12.042>
- Oreiller, M., Nadeau, D. F., Minville, M., & Rousseau, A. N. (2014). Modelling snow water equivalent and spring runoff in a boreal watershed, James Bay, Canada. *Hydrological Processes*, 28(25), 5991–6005. <https://doi.org/10.1002/hyp.10091>
- Sand, K. (1990). Modeling snowmelt runoff processes in temperate and arctic environments. In *PhD Thesis*.
- Skaugen, T., Luijting, H., Saloranta, T., Vikhamar-Schuler, D., & Müller, K. (2018a). In search of operational snow model structures for the future – comparing four snow models for 17 catchments in Norway. *Hydrology Research*, 49(6), 1929–1945. <https://doi.org/10.2166/nh.2018.198>

Overordna konklusjon

On average and over longer periods of time (day/week to month), a simple degree day model will work well. How well will depend on the climatic and topographical variability in the catchment area as well as the representativeness of the temperature measurements.

Over shorter periods of time (within the day and week), the variability in radiation over the day and season and the effect of the terrain, cloud cover and weather type will play a significant role.

According to Magnusson et al. (2011) “*The temperature-index model displayed a flatter slope with a higher intercept than the energy-balance model. This indicates that fast discharge fluctuations were underestimated which suggest that over short time scales the melt rates might be influenced by single energy-balance terms not included in the model. Indeed, this is a known weakness of this model type (Husset al., 2008a).*



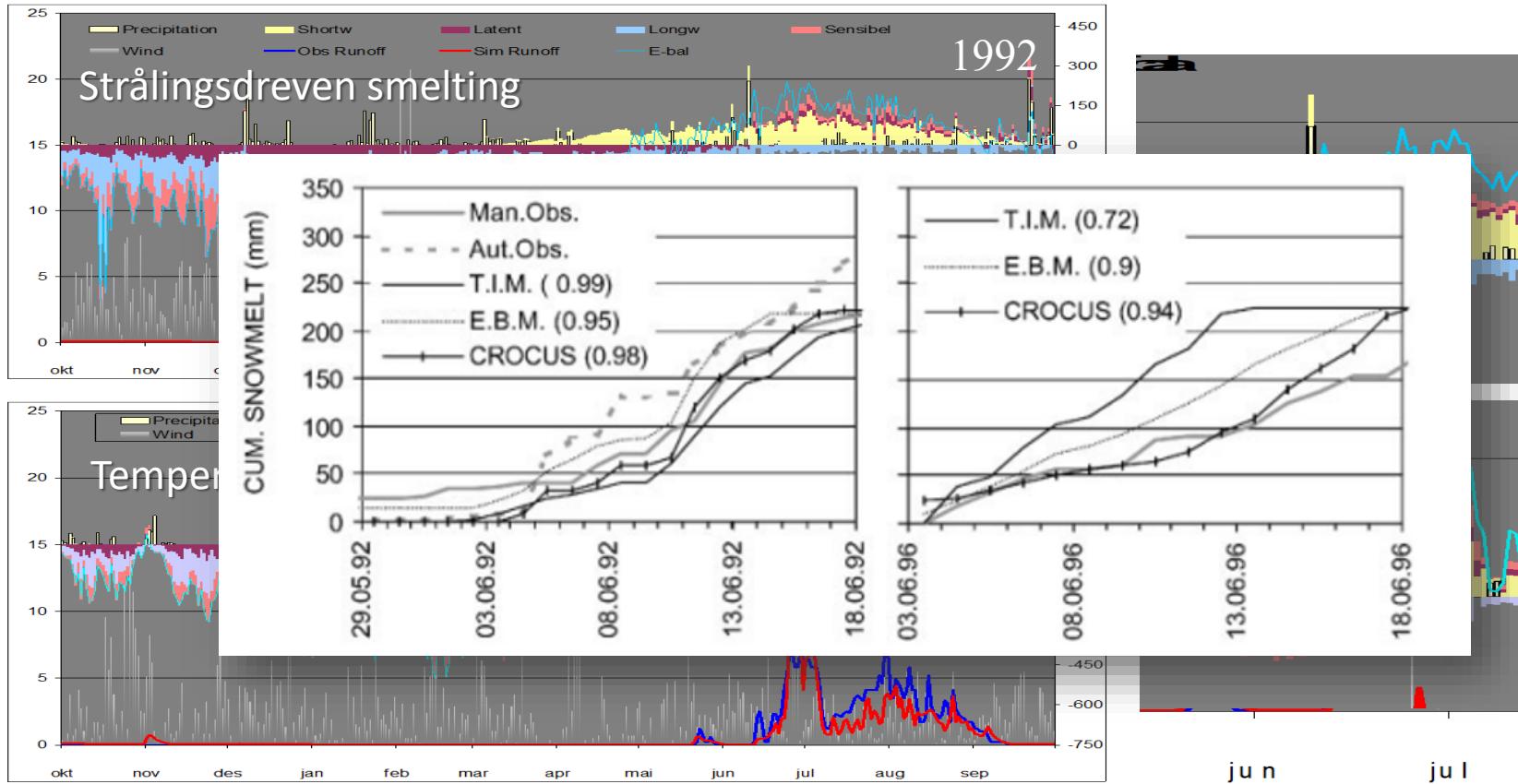
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LATENT HEAT

$$Q_s + Q_l + \textcolor{red}{Q_h + Q_e} + Q_g + Q_r = Q_i + Q_m$$

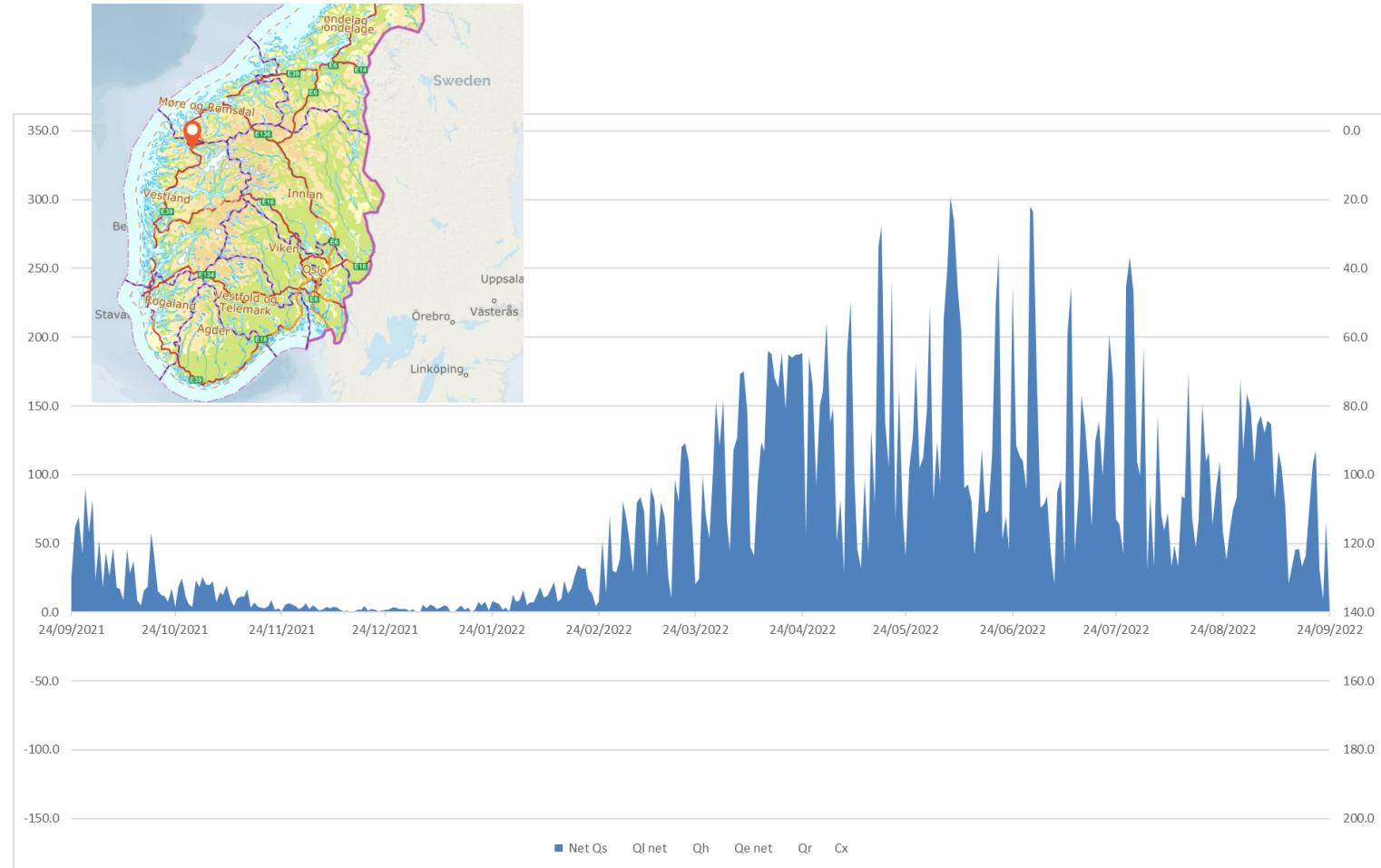
$$Q_e = D_e u_z (e_a - e_s)$$





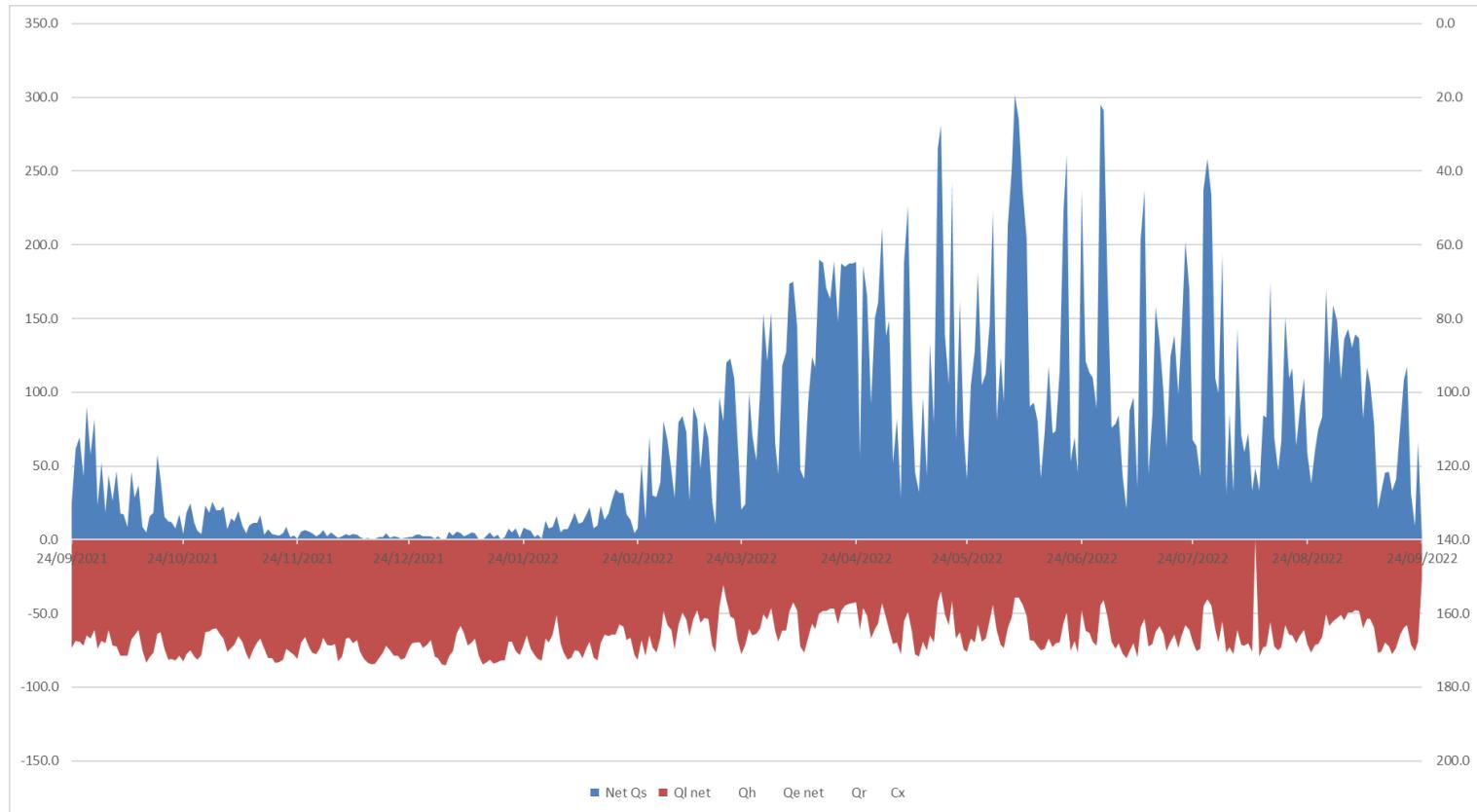


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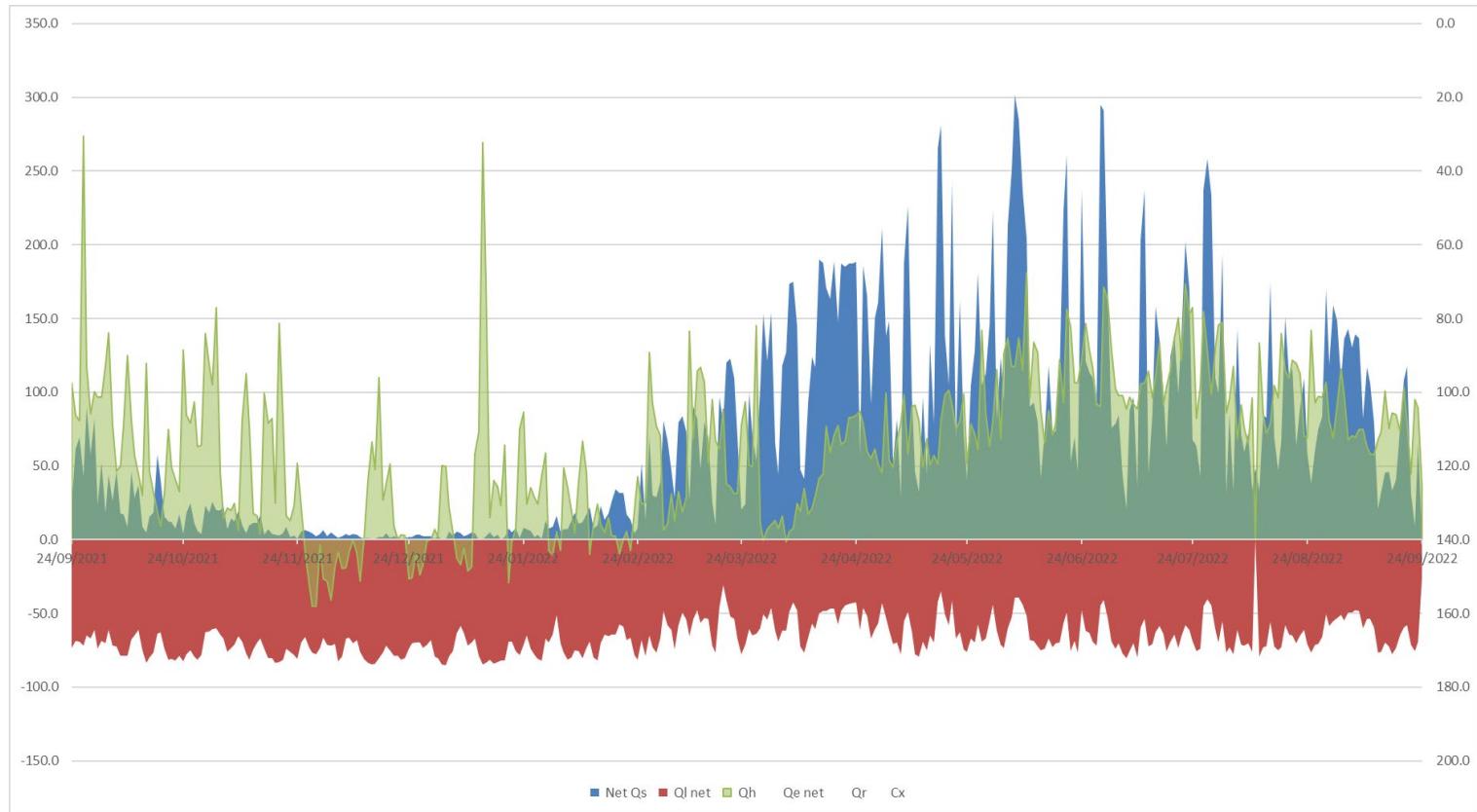


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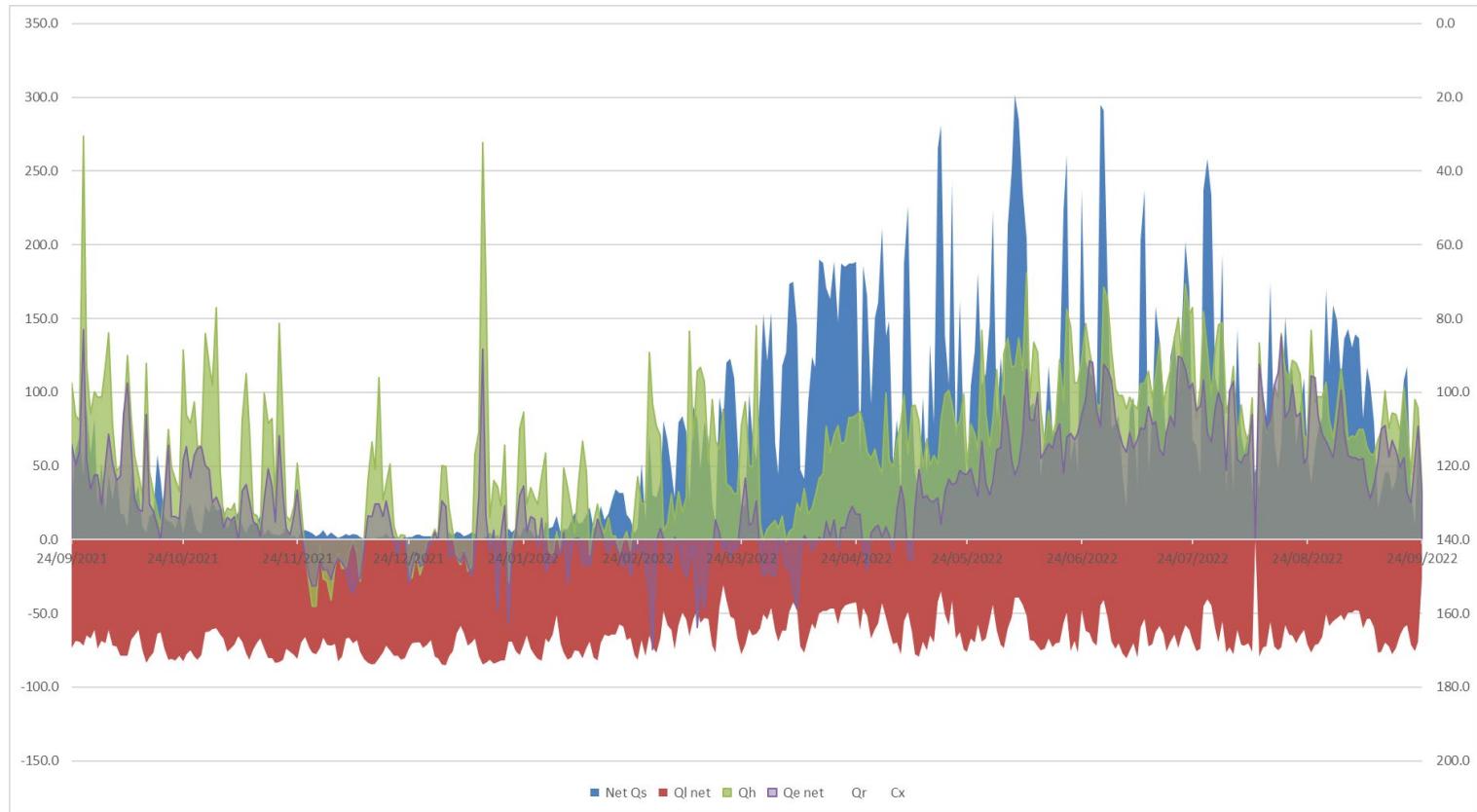


NTNU



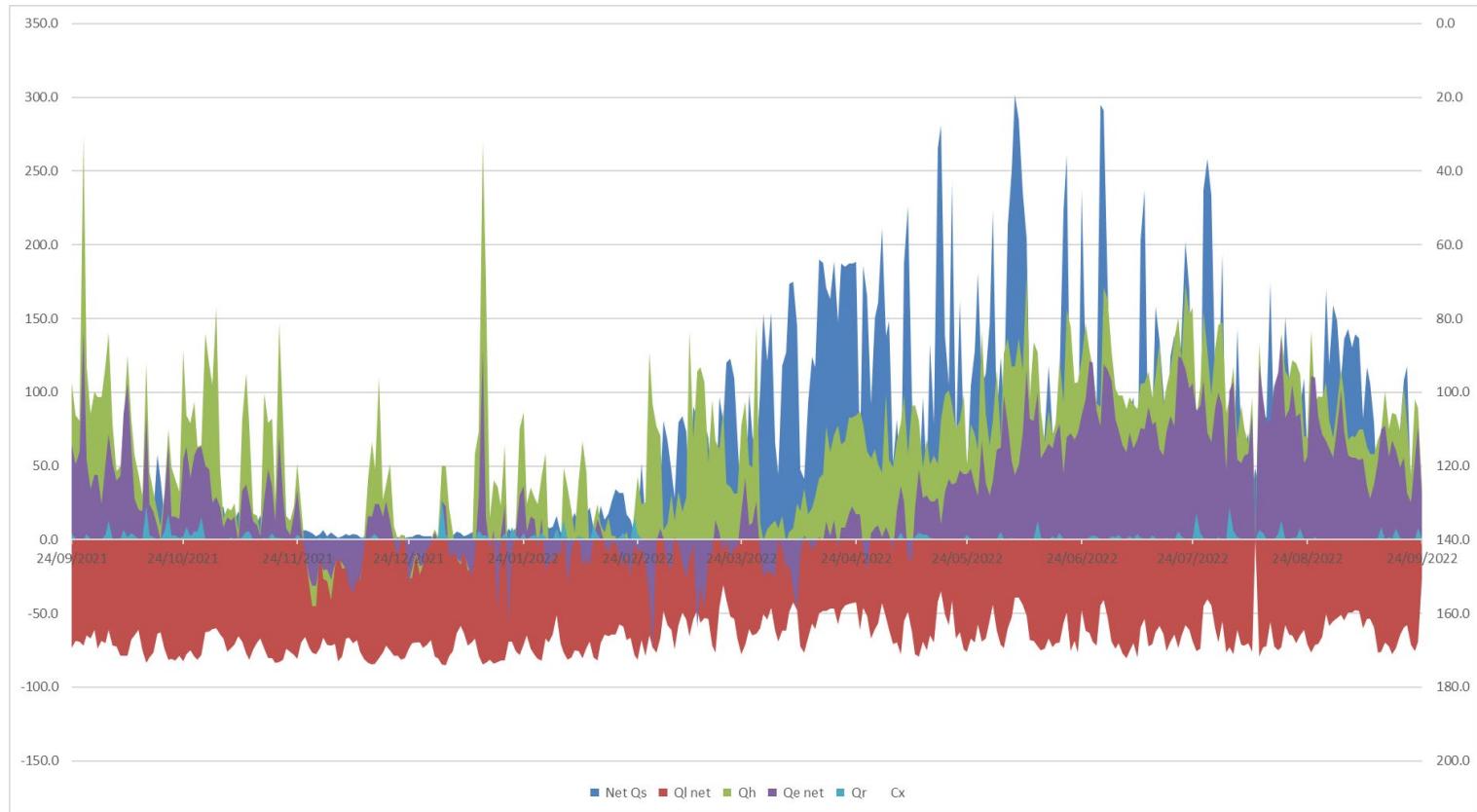


NTNU



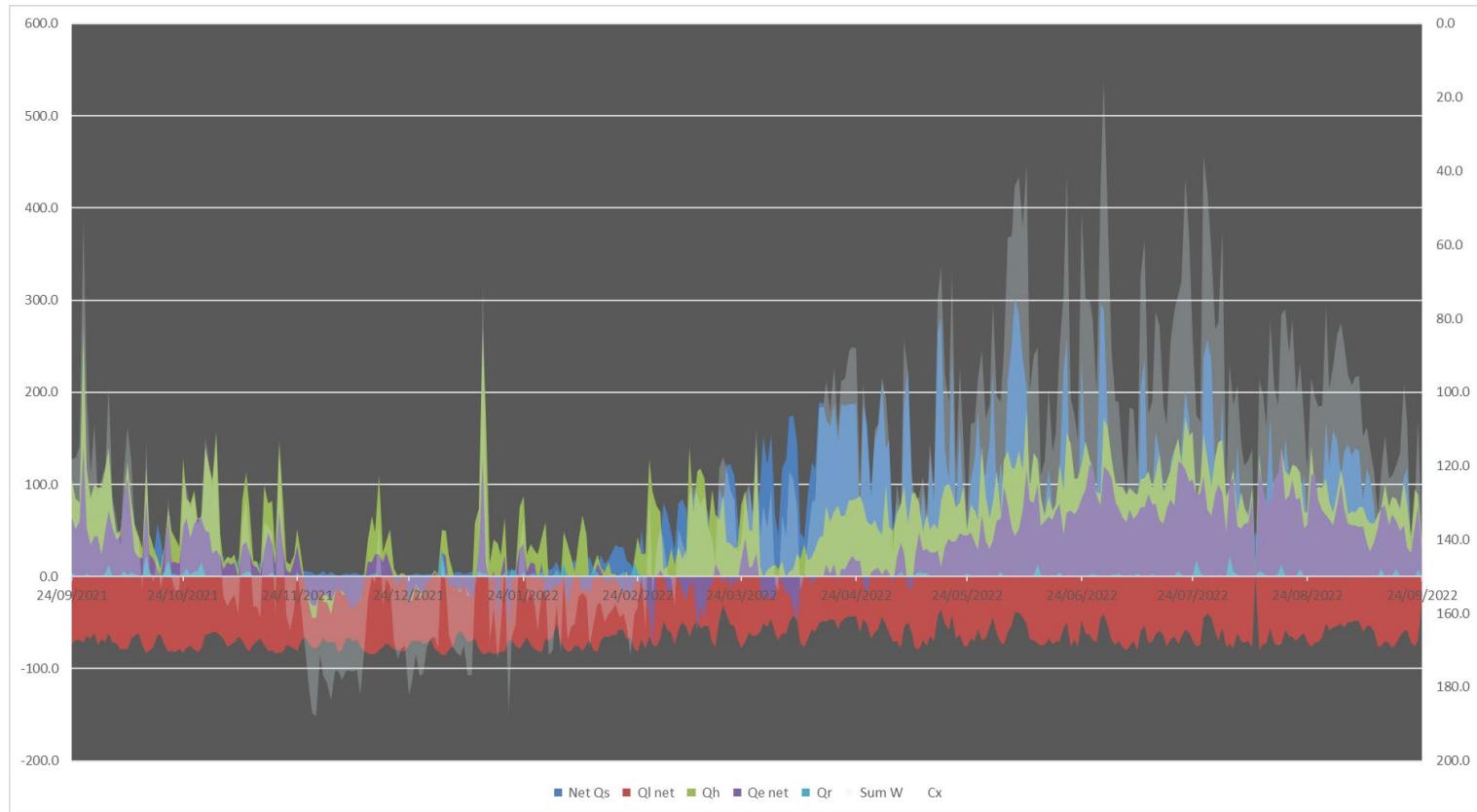


NTNU



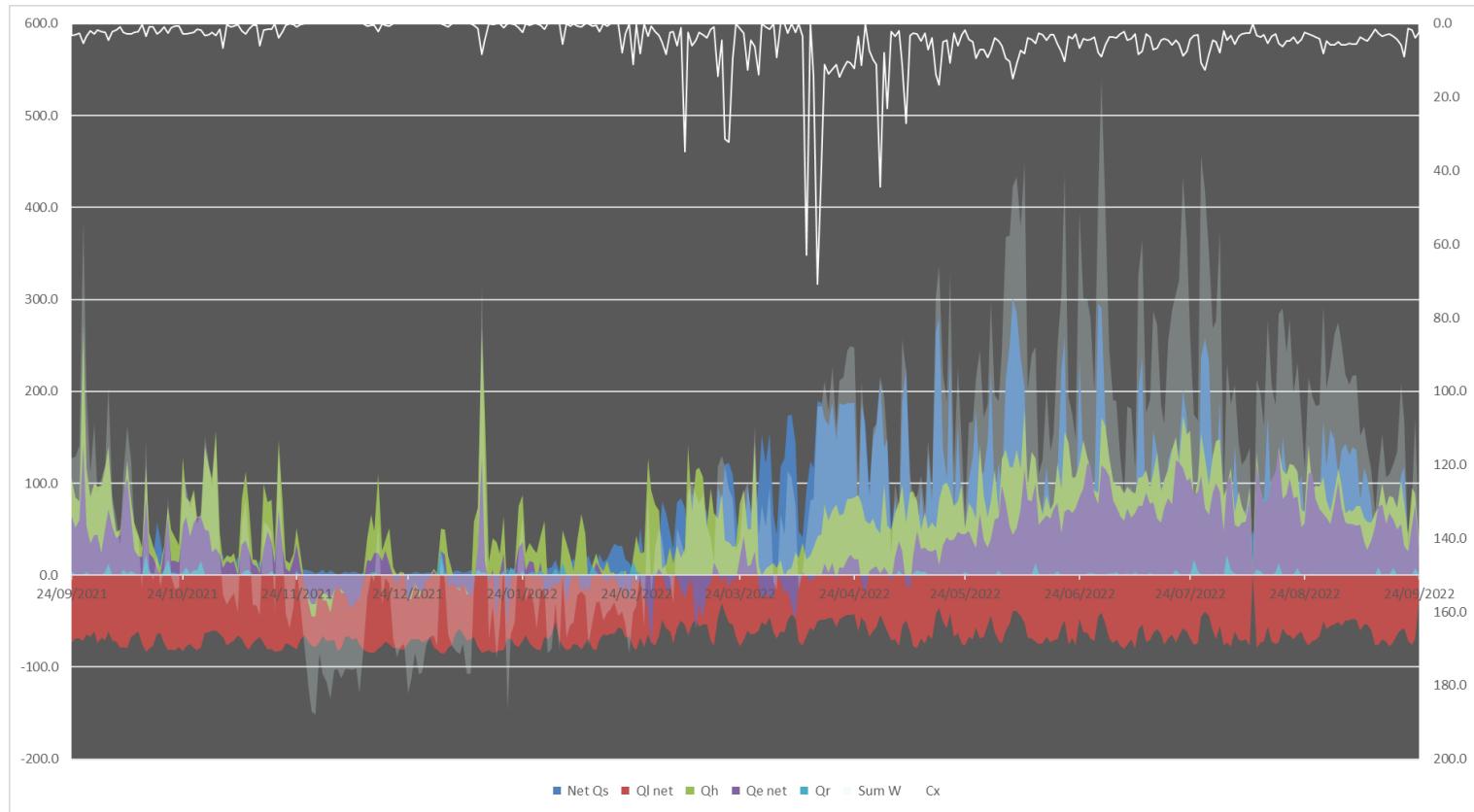


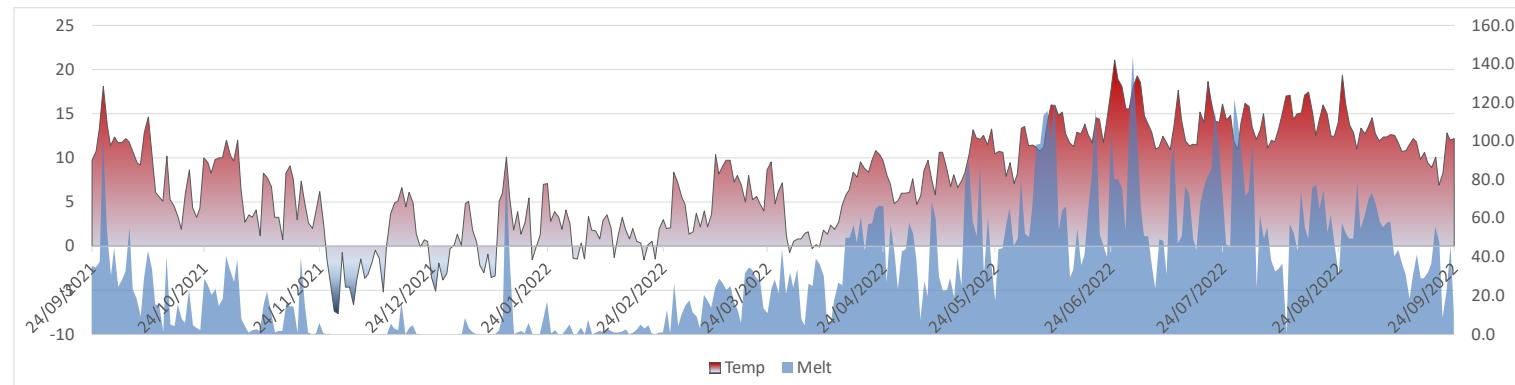
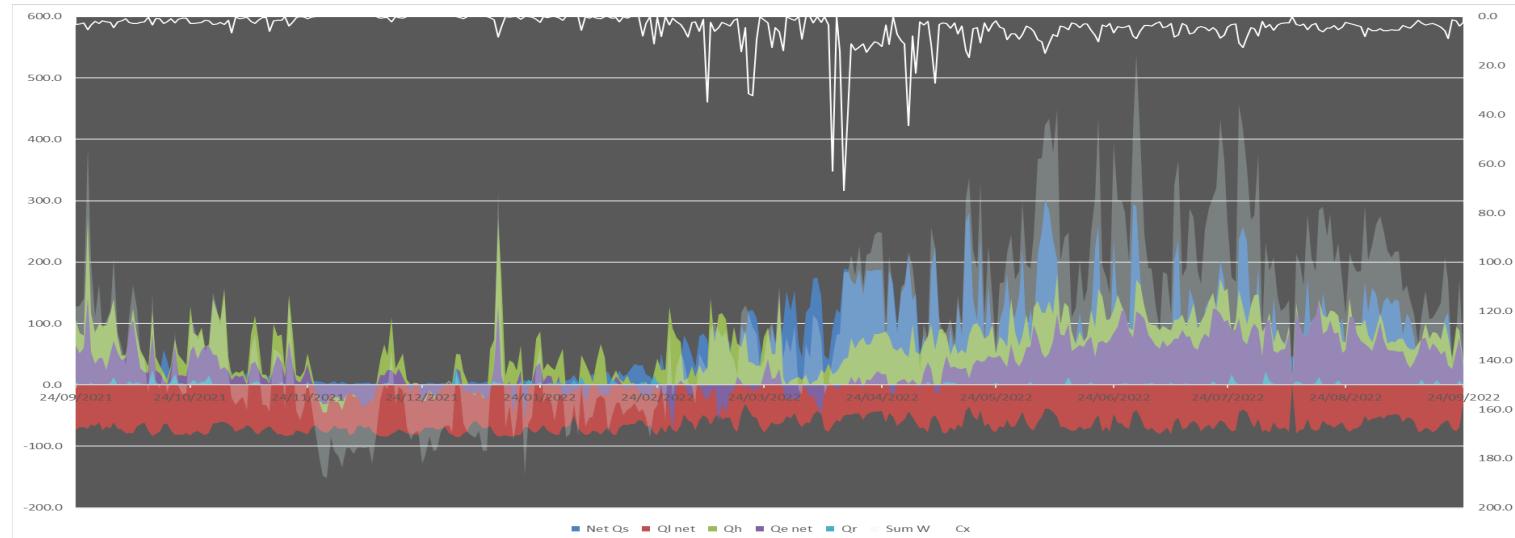
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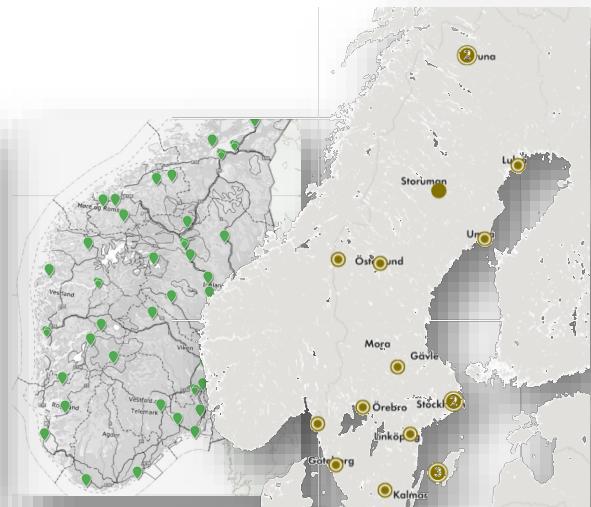
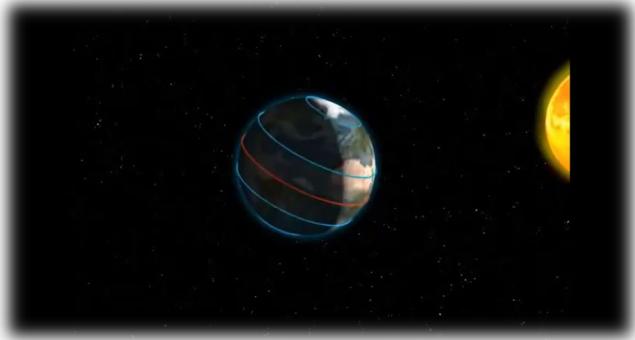


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Har vi det vi treng?



Onsdag 30. november

Tid	Vær	Temp.	Føles som	Nedber mm	Nedbørjanse %	Vind(kast) m/s	Trykk hPa	Luftfuktighet %	Duggpkt.	Skydekke %	Tåke %	Lave %	Mellomh. %
00		4°	1°	0 - 0,6	40	4 (7) ↗	1031	90	2°	100	0	100	99
01		4°	1°	0 - 0,5	30	3 (7) ↗	1031	89	2°	100	0	100	99
02		4°	2°	0 - 0,3	20	2 (5) ↑	1031	88	2°	100	0	100	99
03		4°	4°	0 - 0,2	20	1 (4) ↗	1031	89	2°	100	0	100	95
04		3°	2°	0 -						100	0	100	90
05		4°	2°	0 -						100	0	100	87
06		4°	2°	0 - 0,4	20	2 (3) ↙	1031	84	1°	100	0	99	94
07		4°	2°	0 - 0,4	30	2 (3) ↗	1032	82	1°	96	0	87	88
08		3°	2°	0 - 0,3	20	1 (3) ↙	1032	85	1°	86	0	66	72
09		3°	1°	0 - 0,2	20	1 (2) ↙	1032	89	1°	72	0	57	38
10		3°	3°	10	1 (2) ↙	1032	88	1°	77	0	70	23	
11		3°	3°	10	1 (2) ↙	1033	87	1°	86	0	82	15	
12		3°	3°	5	1 (2) ↙	1033	86	1°	86	0	83	12	



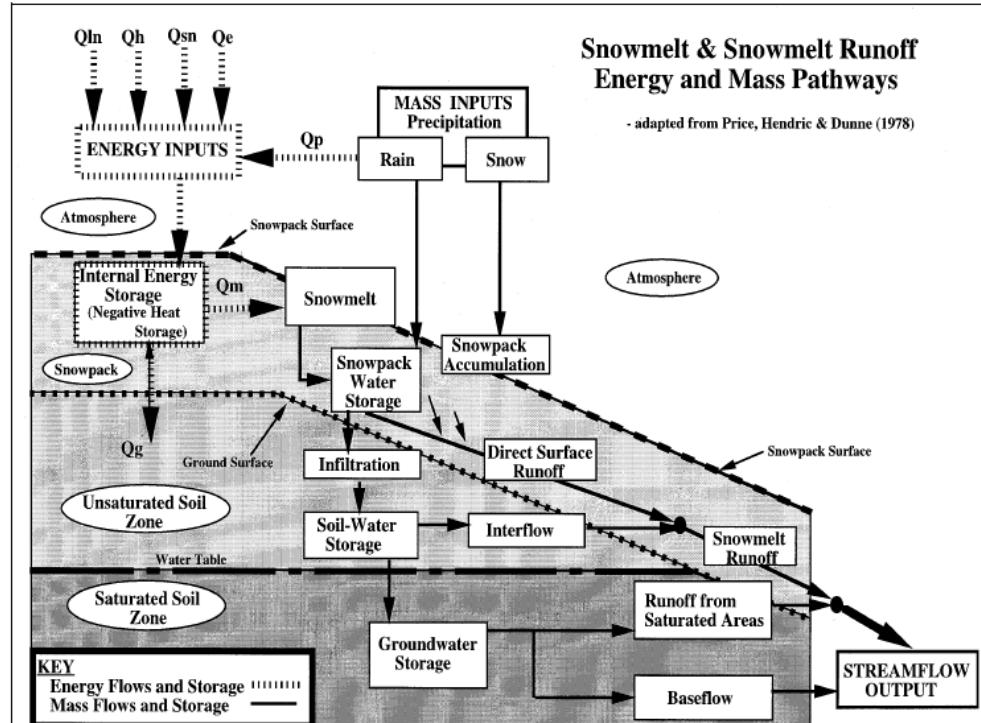
Hvor komplisert må det vere?

$$M1: \quad M = C_{T1} \cdot T_a$$

$$M2: \quad M = C_{T2} (T_a - T_2)$$

$$M3: \quad M = C_{T3} \cdot T_a + C_R(1-a) R_i$$

$$M4: \quad M = C_{T4} \cdot (T_a - T_4) + C_R(1-a) R_i$$



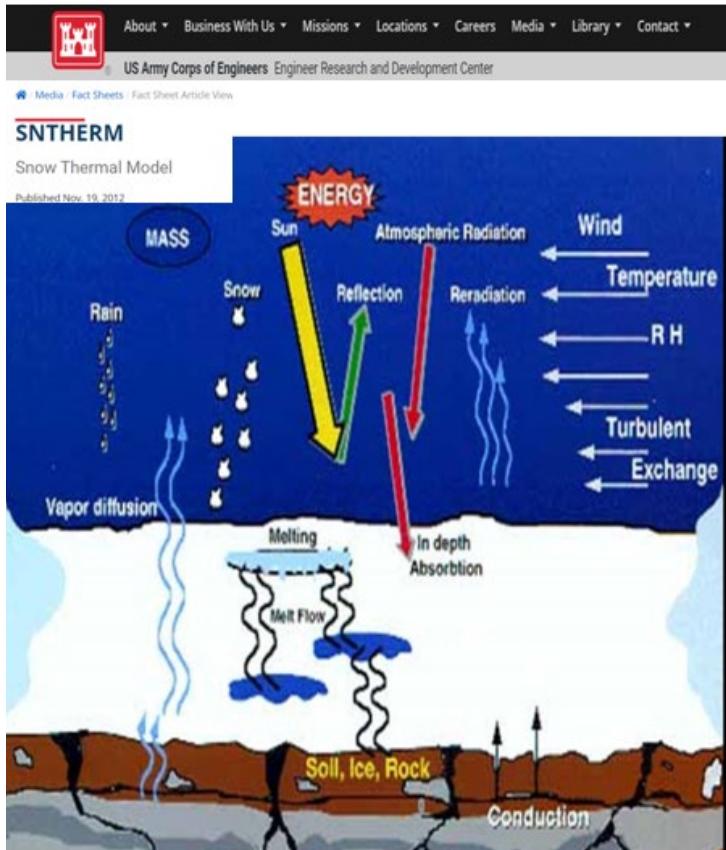
Hvor komplisert må det vere?

$$M1: \quad M = C_{T1} \cdot T_a$$

$$M2: \quad M = C_{T2} (T_a - T_2)$$

$$M3: \quad M = C_{T3} \cdot T_a + C_R(1-a) R_i$$

$$M4: \quad M = C_{T4} \cdot (T_a - T_4) + C_R(1-a) R_i$$



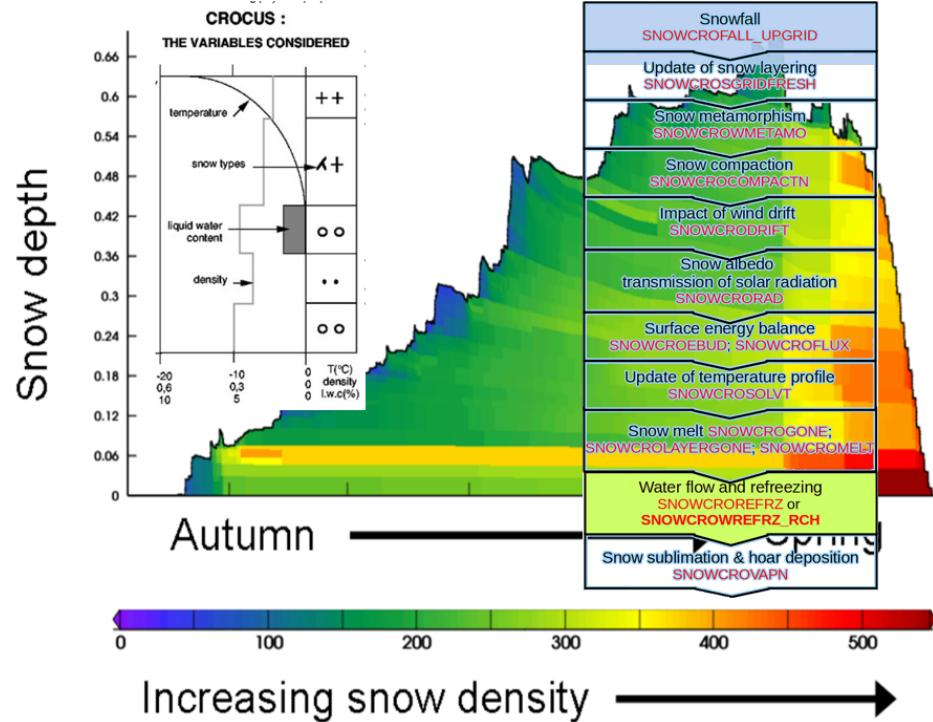
Hvor komplisert må det vere?

$$M1: \quad M = C_{T1} \cdot T_a$$

$$M2: \quad M = C_{T2} (T_a - T_2)$$

$$M3: \quad M = C_{T3} \cdot T_a + C_R(1-a) R_i$$

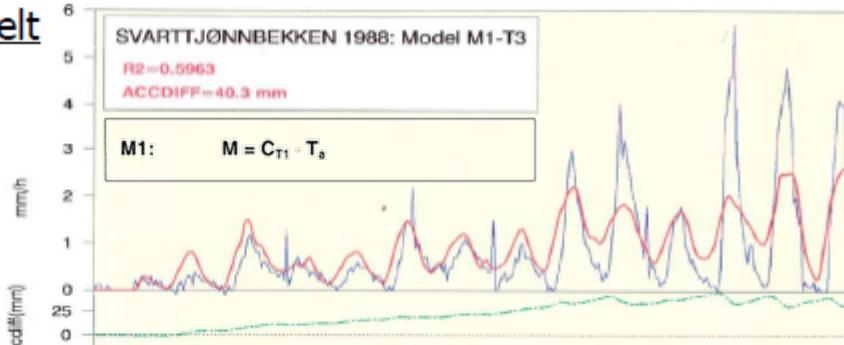
$$M4: \quad M = C_{T4} \cdot (T_a - T_4) + C_R(1-a) R_i$$



Examples from snow melt modelling in Sagelva research catchment by Knut Sand

Upper:

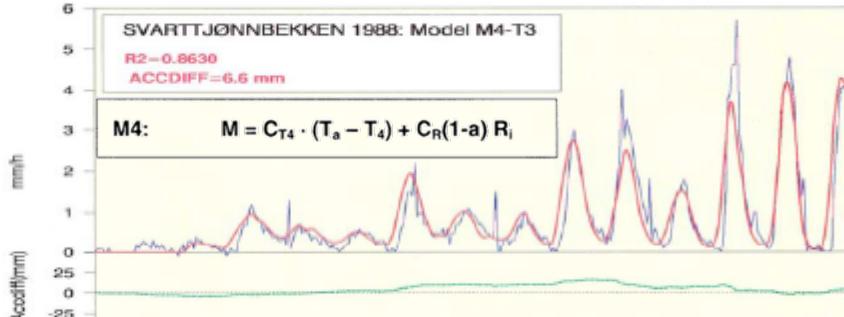
Degree day Model M1



$$M2: M = C_{T_2} (T_a - T_2)$$

Middle:

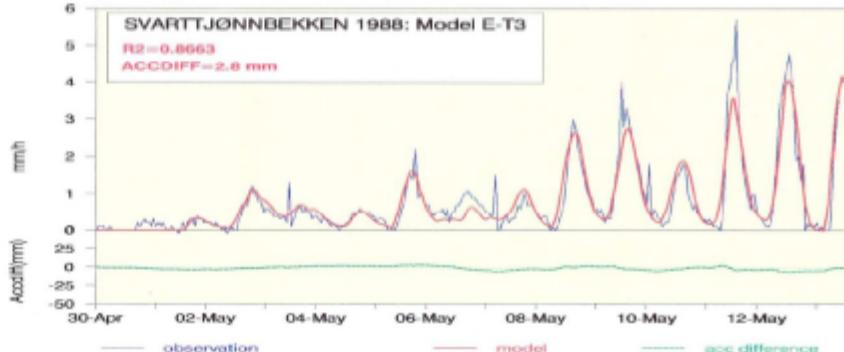
Degree day model M4



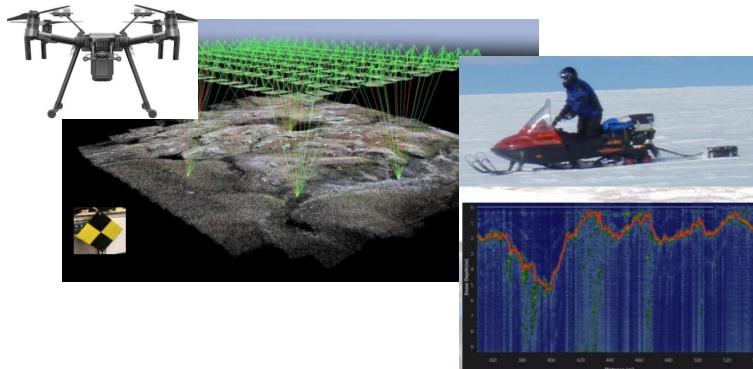
$$M3: M = C_{T_3} \cdot T_a + C_R(1-a) R_i$$

Lower:

Energy balance model



Alt heng i hop med alt...



Frå sofistikert datainnsamling og informasjon

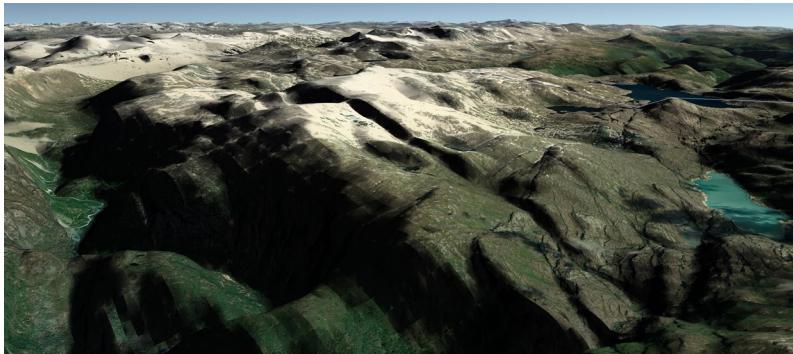
⇒ Simple graddagsmodell – Forsvinn nyttig informasjon?

Sofistikert energibalanse modell

⇒ i lumped hydrologisk modell – Tek ein bruk potensialet?

Værvarsel med høg presisjon og relevant informasjon

=> Utnyttar vi potensialet



Vi har alt vi treng og vel så det – kvifor tek vi det ikkje i bruk?