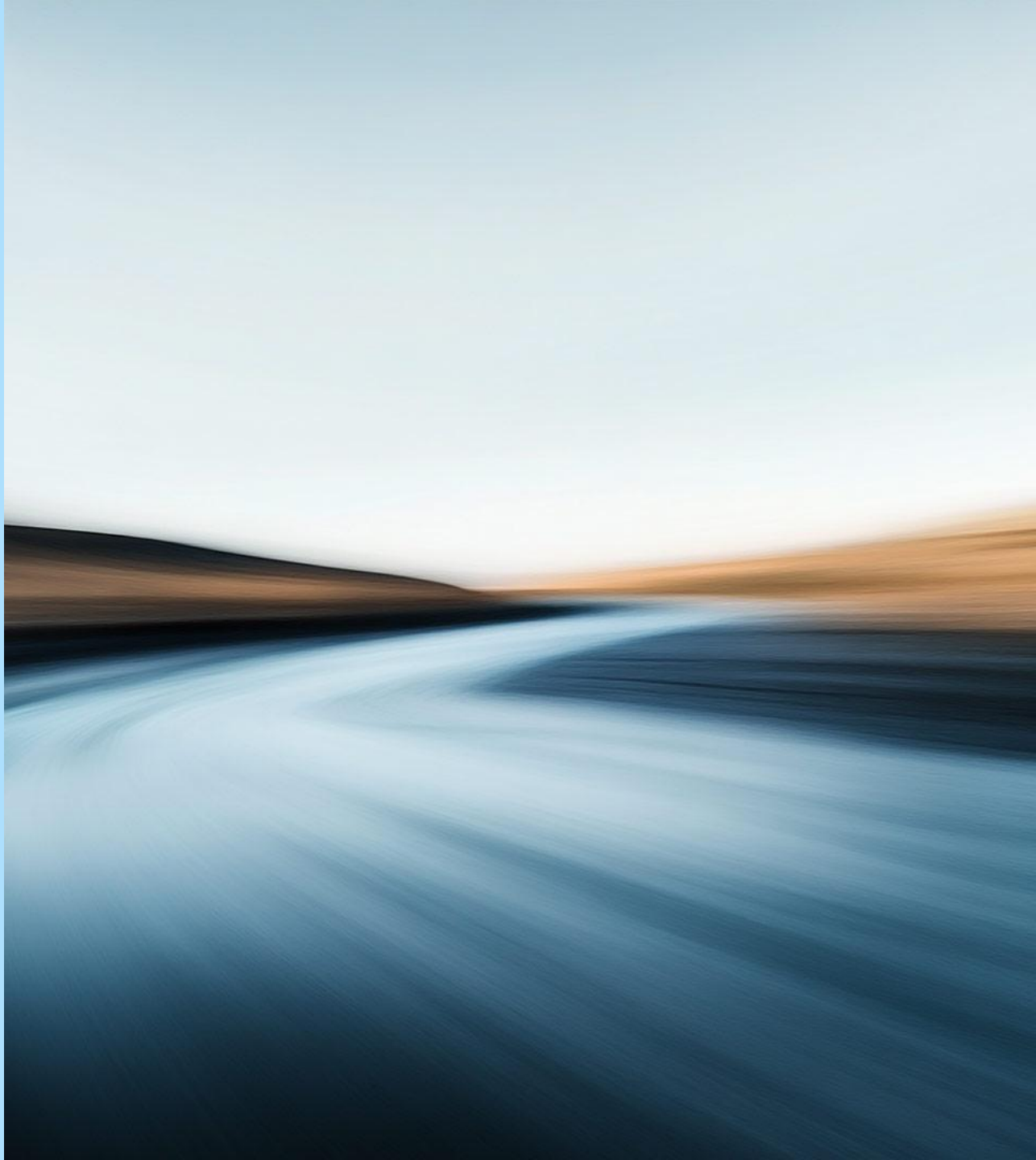
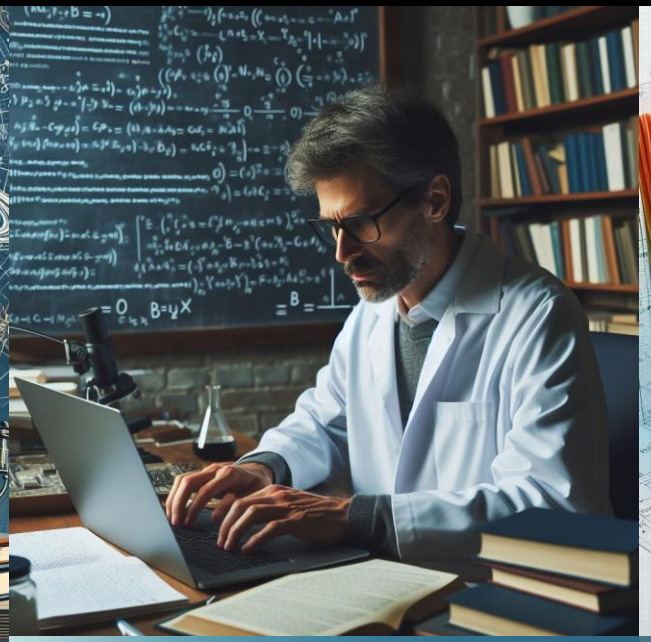
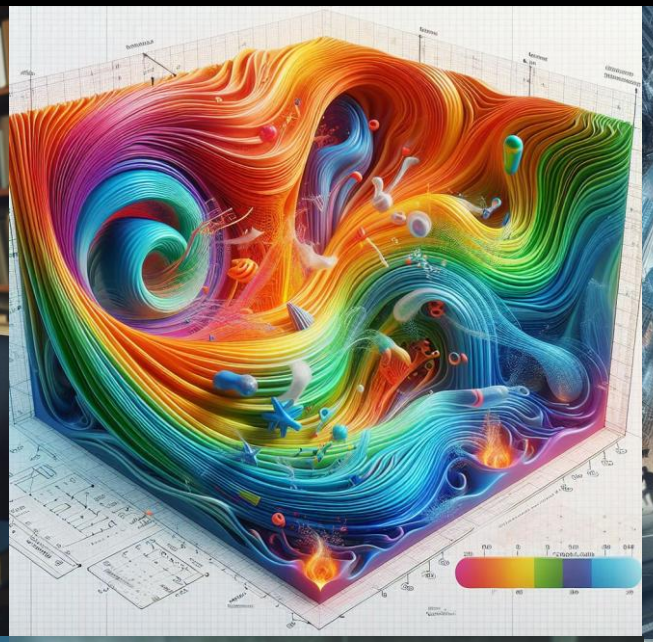
Statkraft

Water, weather and climate services for renewable energy production

Kjetil Thøgersen








Plan for today

- Introduction to Statkraft
- What do we work with in the water, weather and climate department?
- What do we work in in my team?
  - Concrete example of machine learning project
  - Concrete example of R&D project

Statkraft – in brief



Renewable power generation

70 TWh

96%

renewable energy

More than

3 million

energy related contracts traded per year

21.6 GW

installed capacity across our key regions

400+

power plants around the world



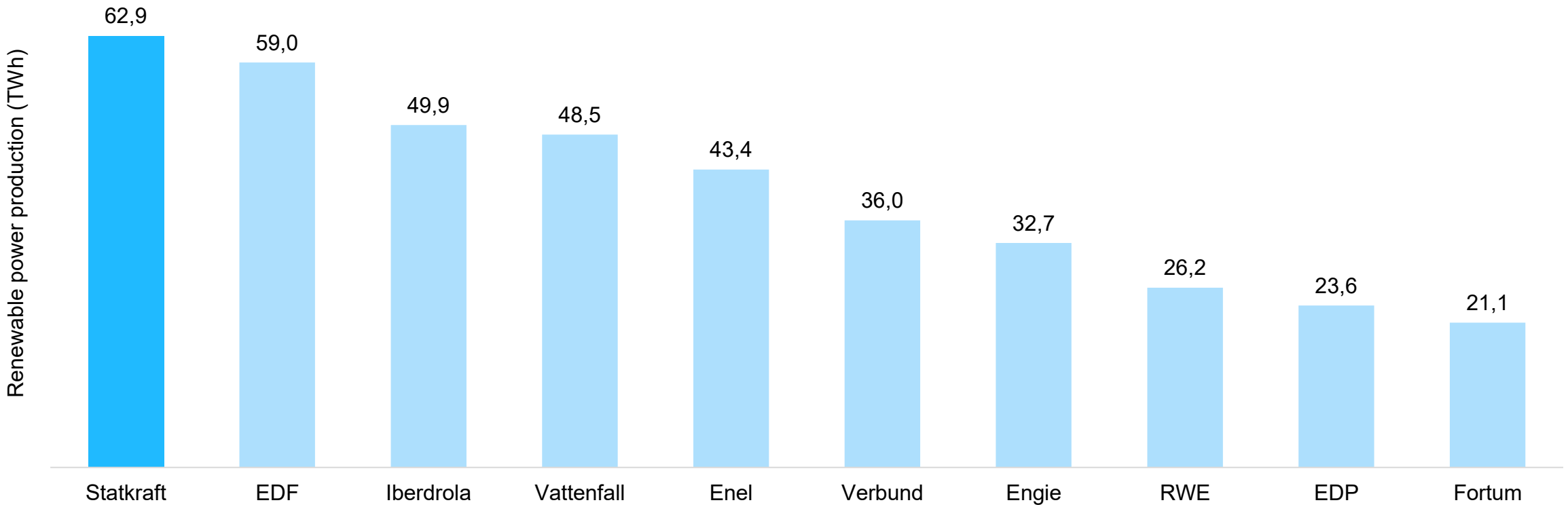
100%

Norwegian state-owned

Statkraft

Europe’s largest producer of renewable energy

Top 10 renewable power producers in Europe 2024



Source: PWC

Statkraft

Statkraft – at the forefront of the energy transition

Installed capacity
22.3 GW

2024 Production
66.3 TWh
96% renewable

More than
3 million
energy related contracts traded per year

Fully owned by the Norwegian state



Installed capacity per Q4 2024
Geographical footprint per Q4 2025

Statkraft

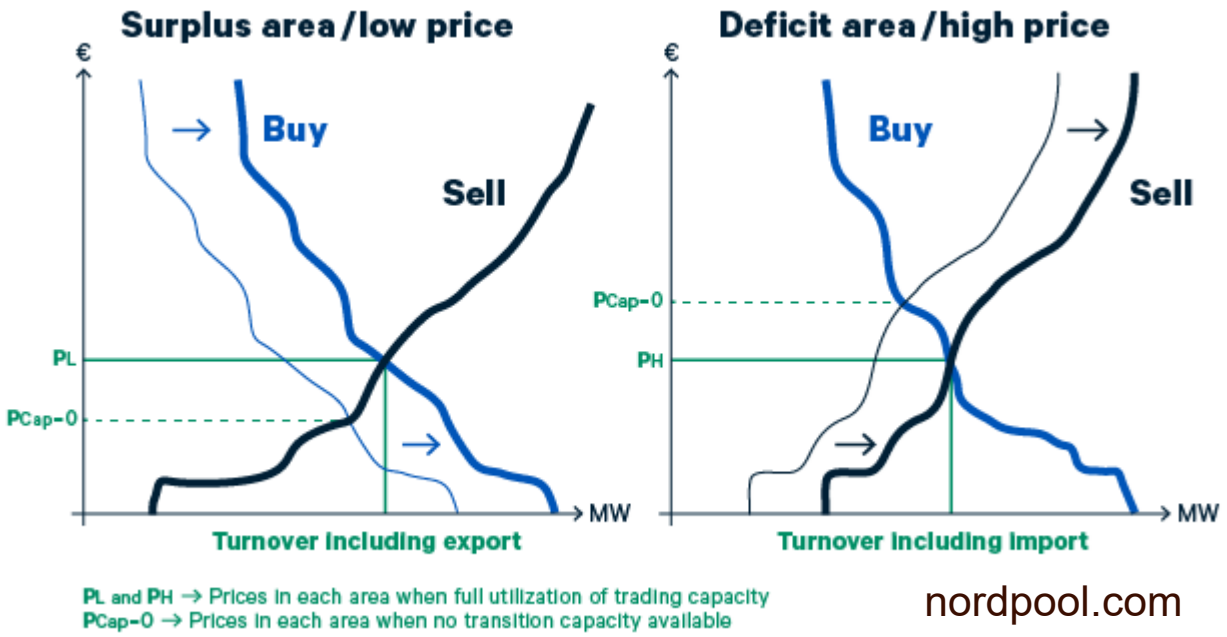


What do we do in the water weather and climate department?

Statkraft



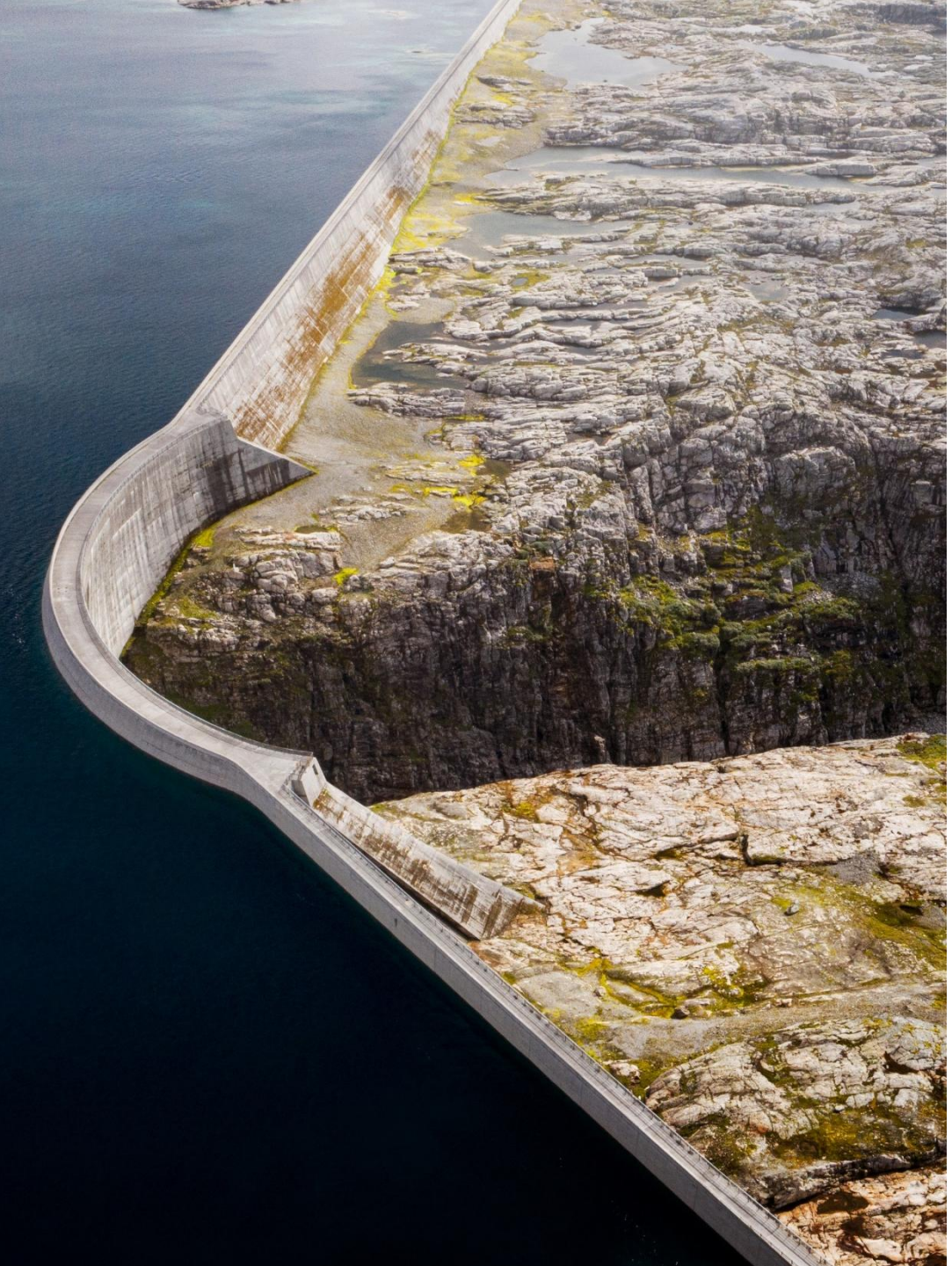
Background: Statkraft places bids in day-ahead, intraday and balancing markets



PL and PH → Prices in each area when full utilization of trading capacity
PCap-0 → Prices in each area when no transition capacity available

nordpool.com

Statkraft

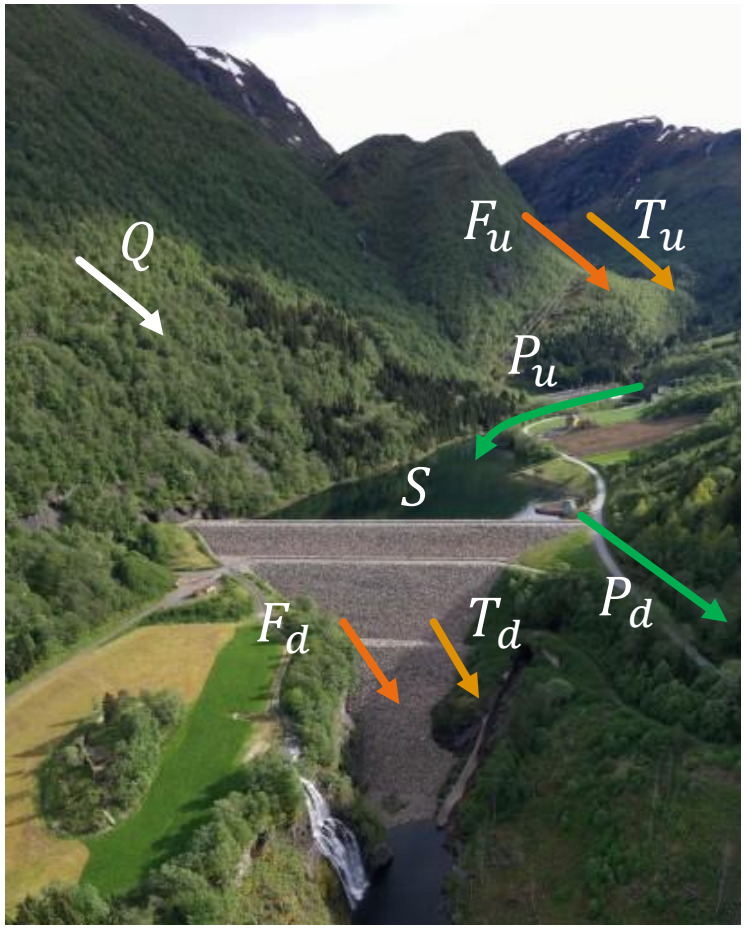


Water inventory

- We need to know how much water Statkraft has available in all reservoir at any given time
- We need to know how much water will arrive in our reservoirs
- We need to know the value of that water

Statkraft

How much water do we currently have?



Inntak Hove / Refsdal Dam

Observed?

Observed

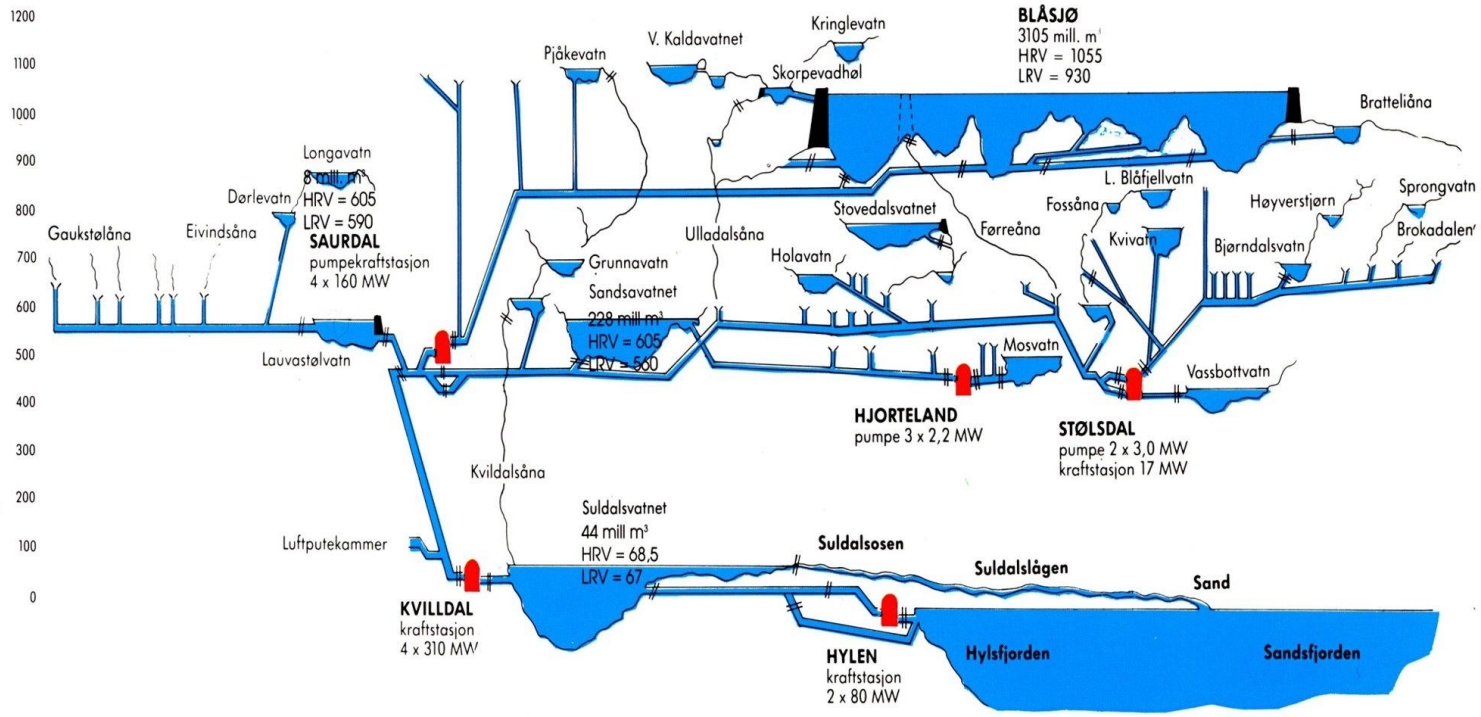
$$Q = \Delta S - P_u + P_d - T_u + T_d$$
$$-F_u + F_d$$

Not observed

Statkraft

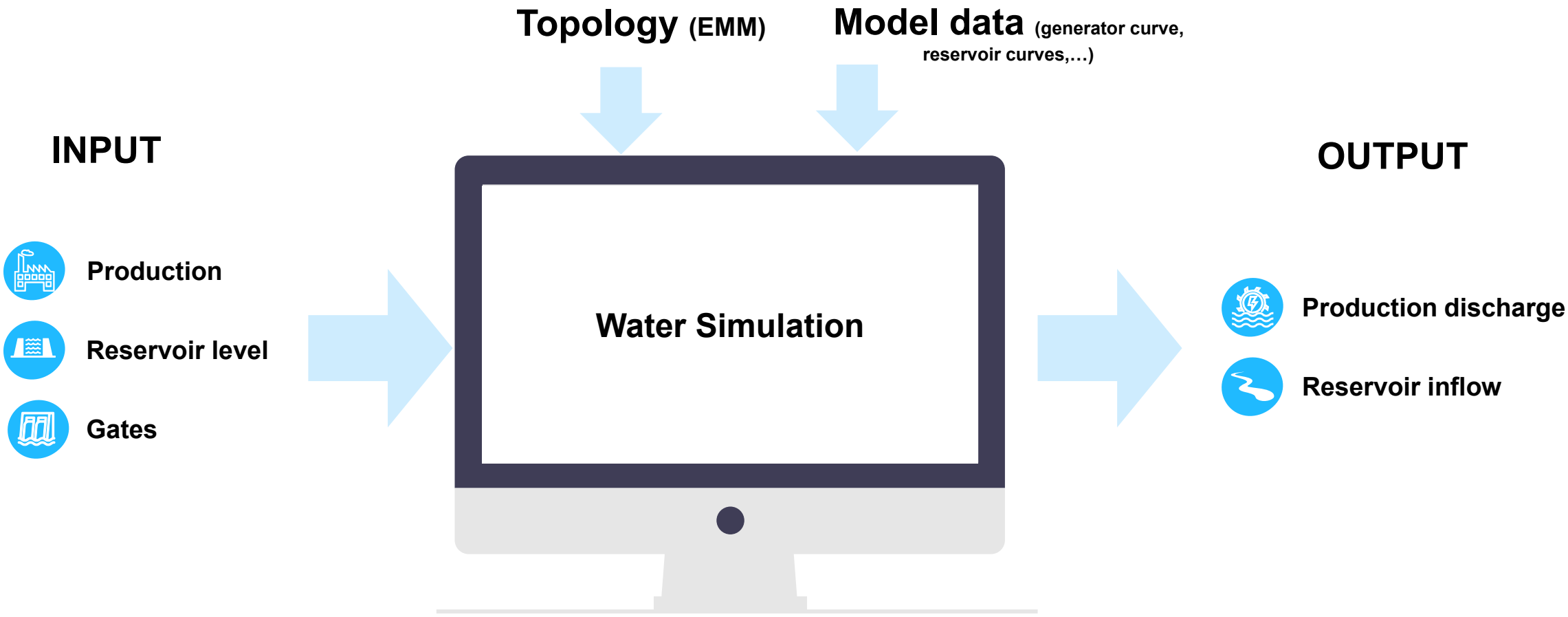
Ulla-Førre

– an example of a complex power system in which computing inflow can be challenging



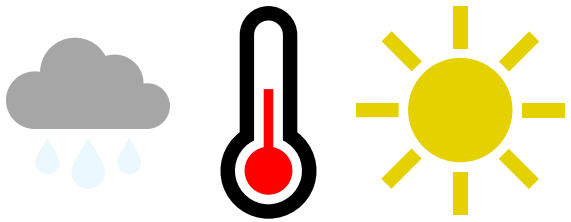


How much water do we currently have?



Statkraft

When will new water arrive in our systems?



+ humidity

Hydrological model



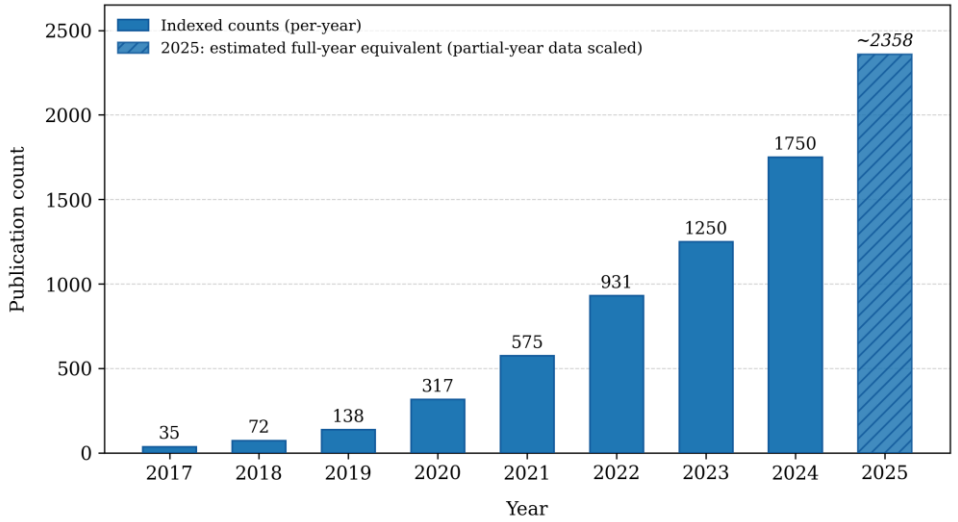
Statkraft

Inflow is predicted with physics based models

- SHyFT
- Run for predictions at different time-scales
  - Short term (10 days)
  - Medium term (5 years)
  - Long term (40 years)
- In operation today



Trends in hydrological modeling
Data driven inflow



Jouval Somer, 2025

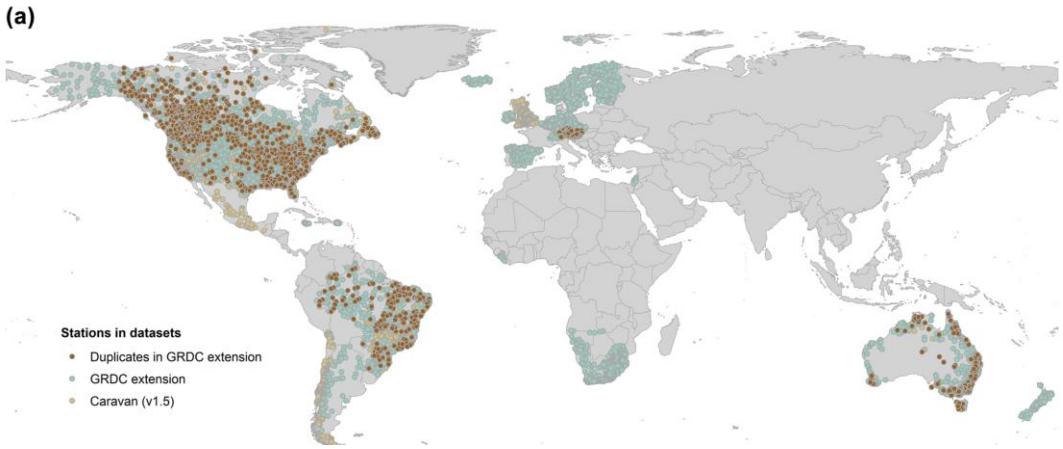
09 SEPTEMBER 2024 / PAPER / CODE

HESS OPINIONS: NEVER TRAIN A LONG SHORT-TERM MEMORY (LSTM) NETWORK ON A SINGLE BASIN

Never, never, (really never!?) train an LSTM on a single basin. Or should you?

READ THE POST

Neuralhydrology.github.io



Färber et al, GRDC-Caravan: extending Caravan with data from the Global Runoff Data Centre, 2025

Statkraft

Measurements needed for model correction and validation

We measure

- Precipitation
- Water level
- Snow depth
- Wind direction
- Air temperature
- Irradiation
- Wind speed
- Water temperature









Weather station data supplied with field work

Water flow in rivers



Snow depth

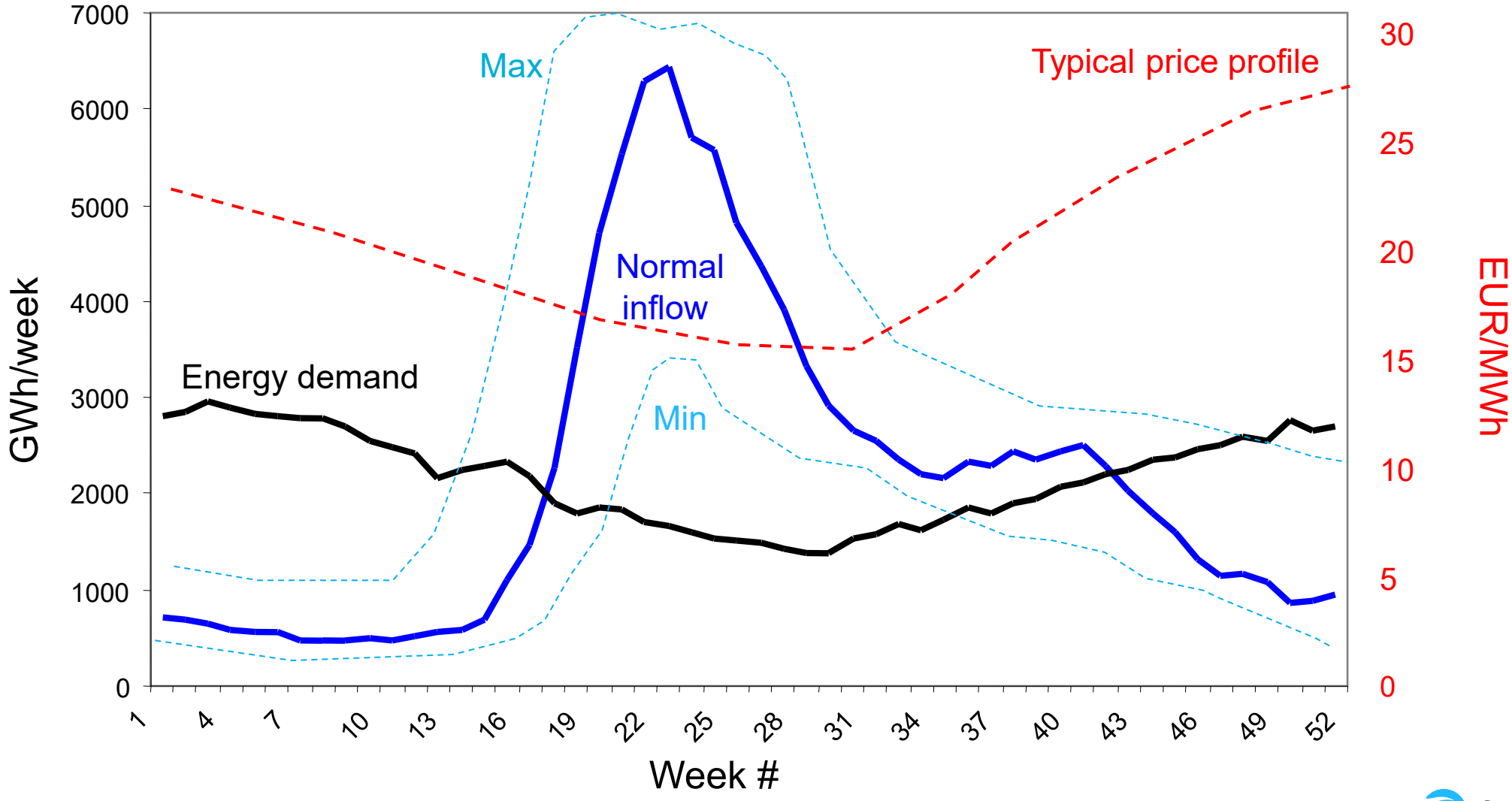


Snow density



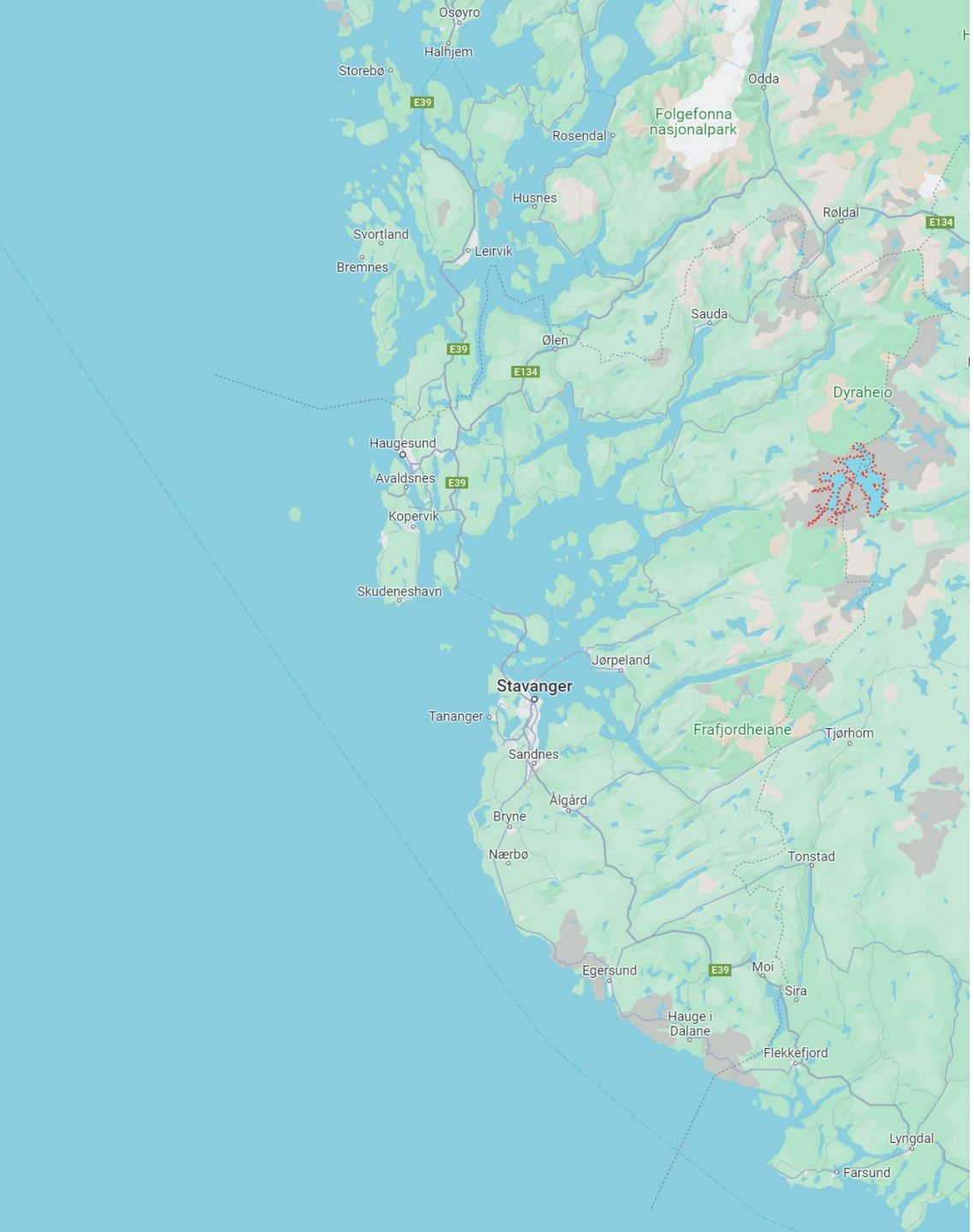
Maintain weather stations




7000
6000
5000
4000
3000
2000
1000
0
GWh/week
30
25
20
15
10
5
0
EUR/MWh
Max
Typical price profile
Normal
inflow
Energy demand
Min
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
52
Week #

Statkraft


Osøyro
Halhjem
Storebø
Odda
Hardangervidda nasjonalpark
Folgefonna nasjonalpark
Rosendal
Husnes
Svortland
Leirvik
Bremnes
Røldal
Haukeligrend
Sauda
Ølen
Hovden
Dyraheio
Haugesund
Avaldsnes
Kopervik
Skudeneshavn
Møsvatn Austfjell
Rjukan
Tuddal
Rauland
Åmot
Seljord
Dalen
Bø
Telemarkskanalen natur- og kulturpark
Valle
Rysstad
Jørpeland
Stavanger
Tananger
Sandnes
Frafjordheiane
Tjørhom
Bortelid
Ålgård
Bryne
Nærbø
Tonstad
Evje
Egersund
Moi
Sira
Hauge i Dalane
Flekkefjord
Vennesla
Lillesand
Kristiansand
Lyngdal
Farsund
Søgne
Mandal
Skagerrak
Arendal
Nedenes
Grimstad
Tvedestrand
Risør
Sundebru
Kragerø
Prestestranda
Skien
Porsgrunn
Stathelle
Langesund
Larvik
Stavern
Sandefjord
Tønsberg
Hokksund
Drammen
Kongsberg
Notodden
Hønefoss
Jessheim
Årnes
Lillestrøm
Oslo
Lørenskog
Sandvika
Asker
Kolbotn
Ski
Drøbak
Askim
Mysen
Holmestrand
Horten
Moss
Rakkestad
Rolvsøy
Fredrikstad
Halden
Strømstad
Ytre Hvaler Nasjonalpark
Kosterhavets Nationalpark
Tanumshede
Lysekil kommune
E39
E134
E18
E6
4

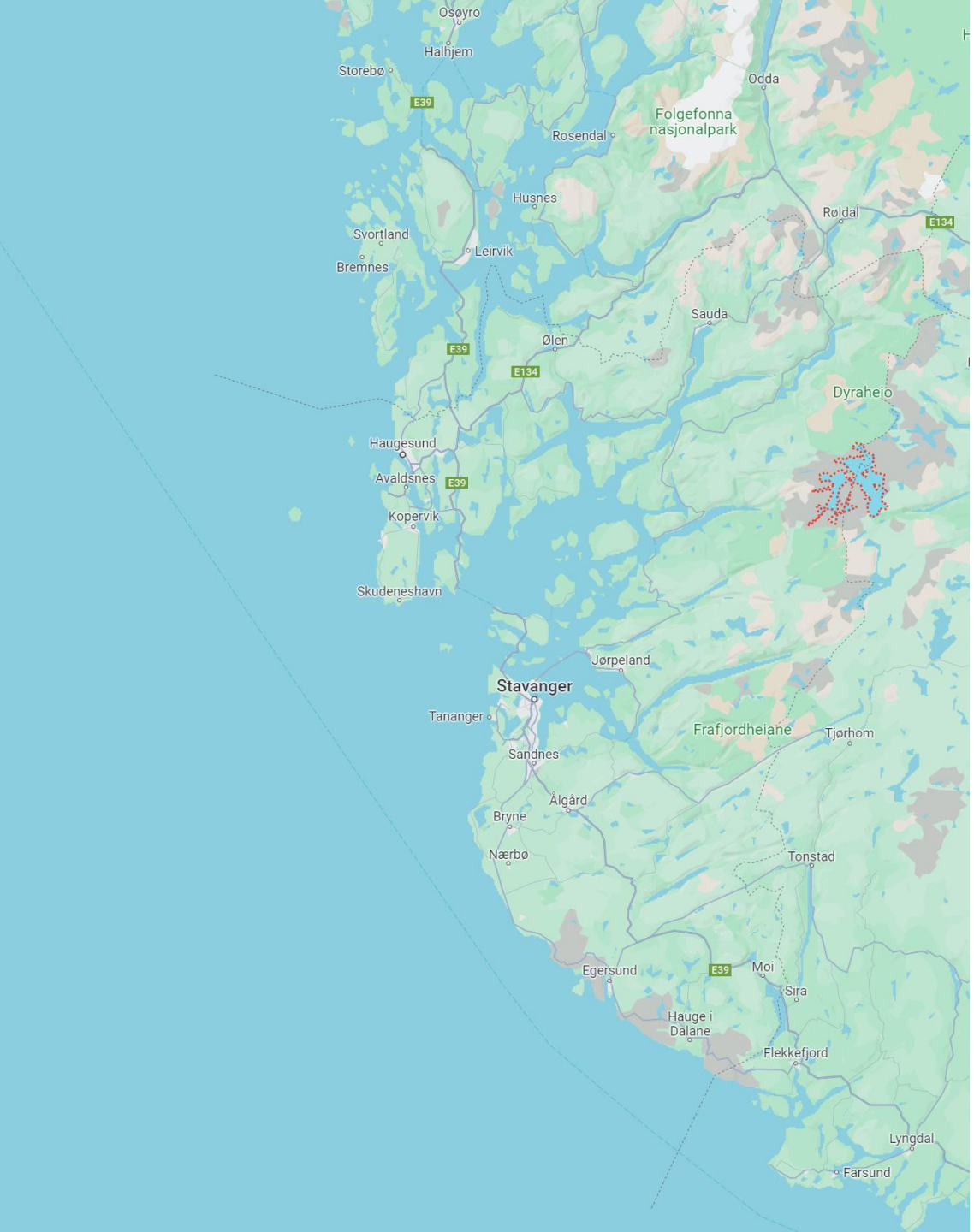


What is the value of the water?

Water value:

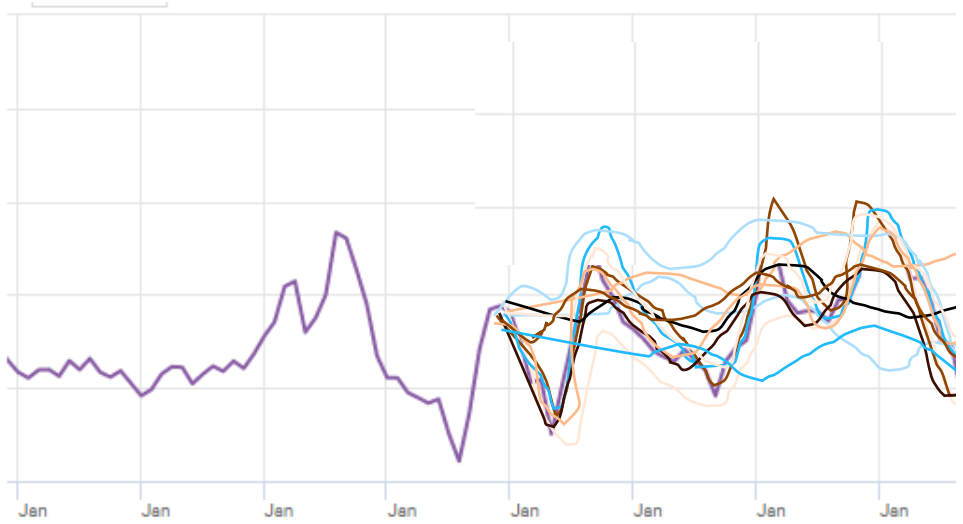
alternative cost of producing one extra MWh from the reservoir.

Statkraft

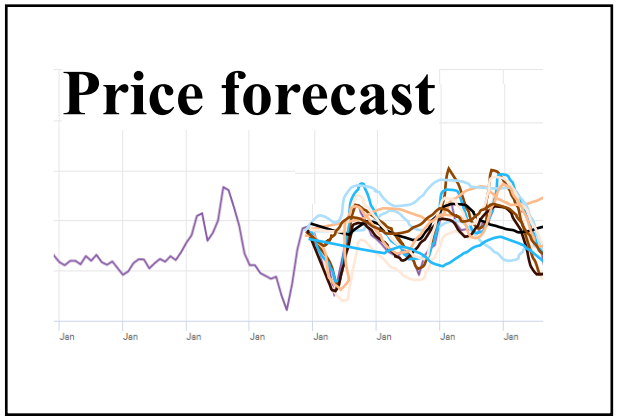


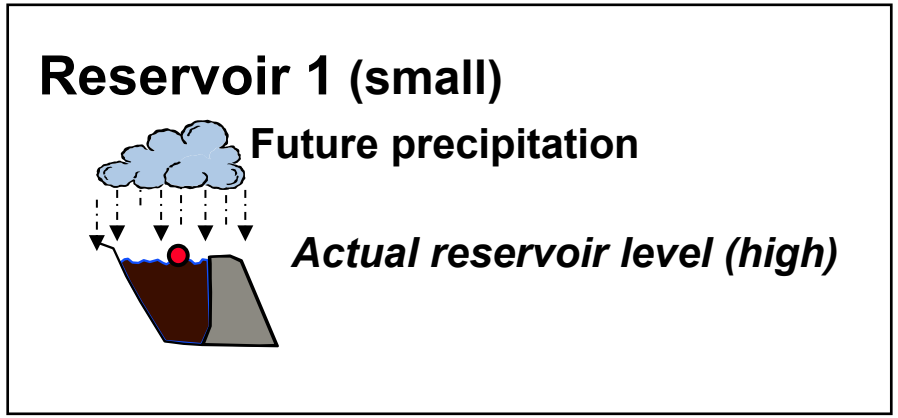
What is the value of the water?

- It can take up to 5 years to fill Blåsjø if it is empty
- 5 year price forecasts needed
- Reservoir levels and synthetic weather scenarios are used as inputs to price forecast models

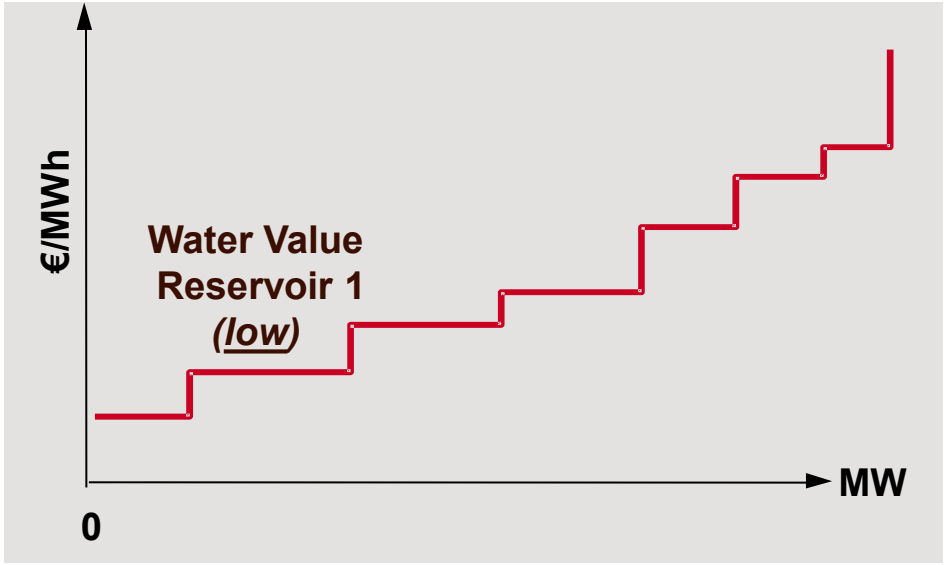


Water values simplified





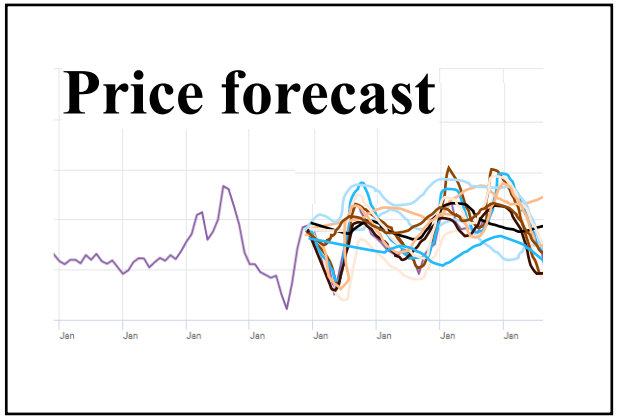
Water Value as function of production volume using all reservoirs

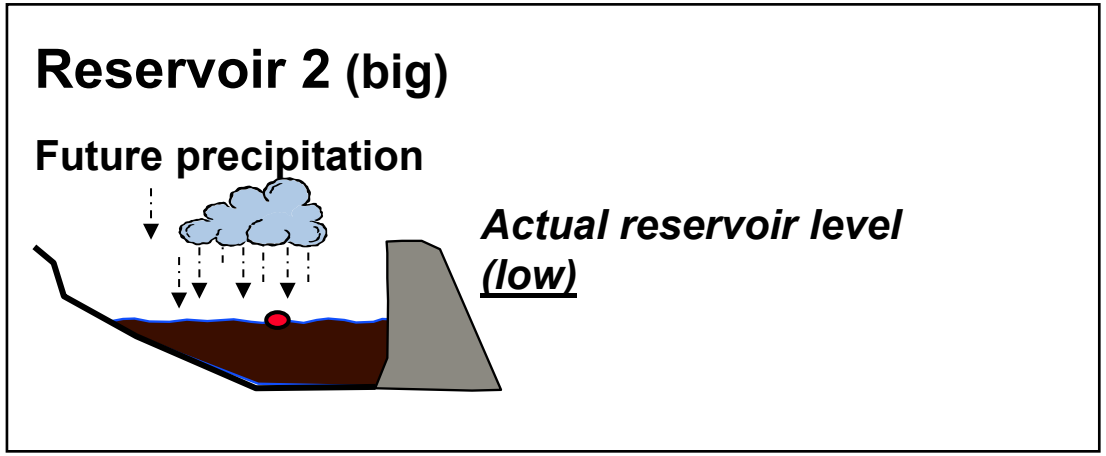


Water value = alternative cost of producing one extra MWh from the reservoir.

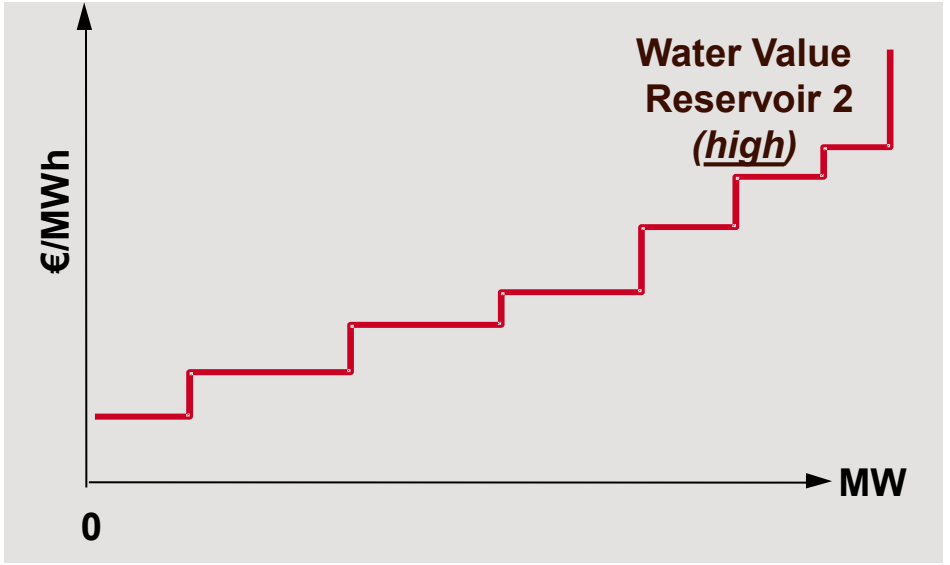
Statkraft

Water values simplified





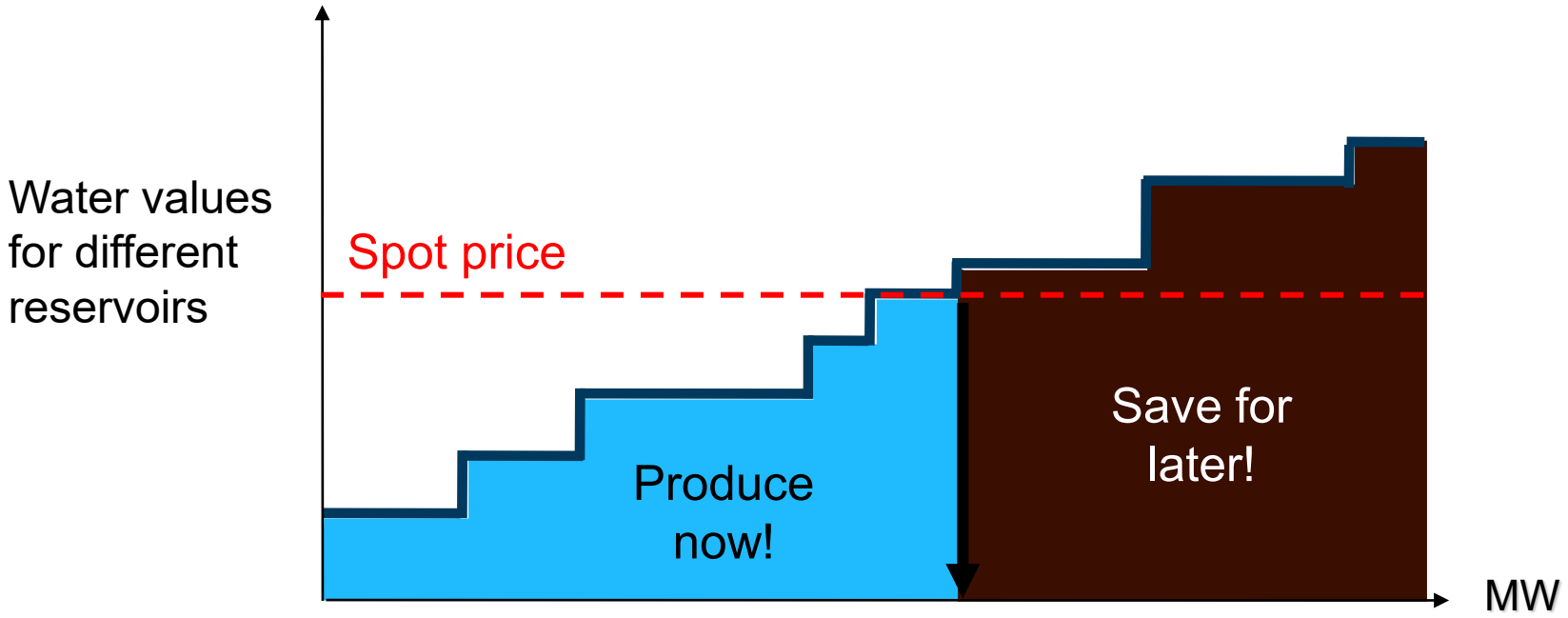
Water Value as function of production volume using all reservoirs



Water value = alternative cost of producing one extra MWh from the reservoir.

Statkraft

Water values simplified



Statkraft

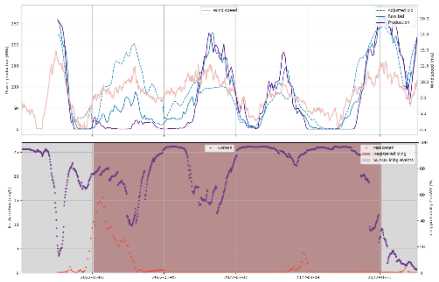
Weather and climate team

Statkraft

Develop **weather and climate services** for costumers across Statkraft

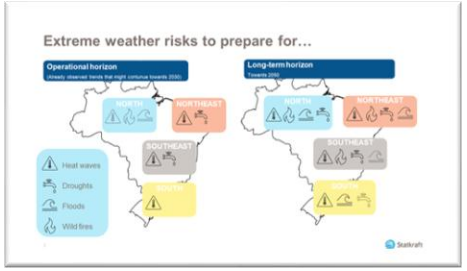
- Forecast weather events for wind and solar production
- Example for today: Forecasting of icing on wind turbines

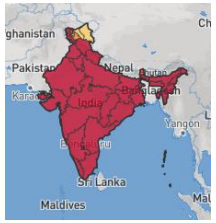


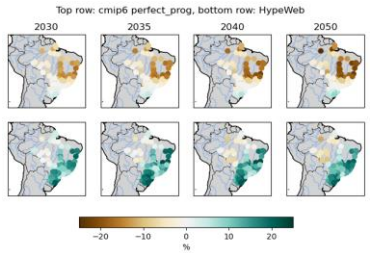


Physical **climate knowlegde** hub

- Provide knowledge on climate change
- Provide climate adjusted power production and inflow forecasts
- Participate in and coordinate research projects on weather, hydro, solar and wind production



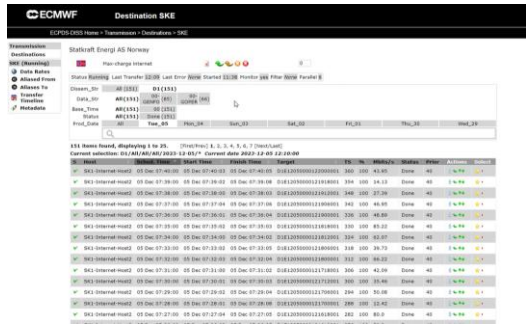




climatefutures

Weather forecast **contact**

- Provide domain knowledge on forecast quality and availability
- Communicate updates and be contact point between ECMWF and Statkraft



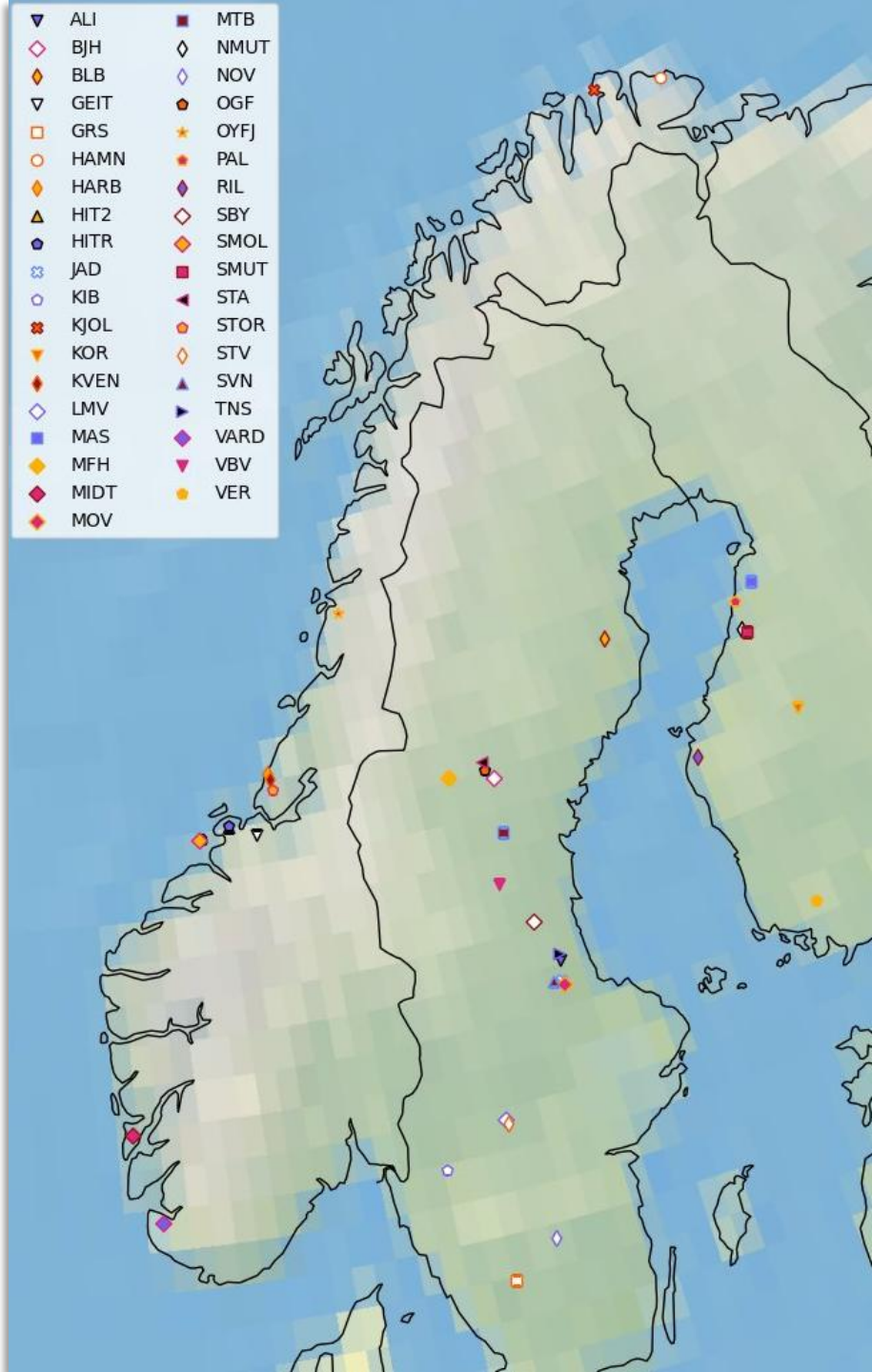
Statkraft

Example of machine learning project

Wind turbine icing

- We operate 42 wind parks in the Nordics
- A common issue during the winter is energy loss due to icing on the turbine blades

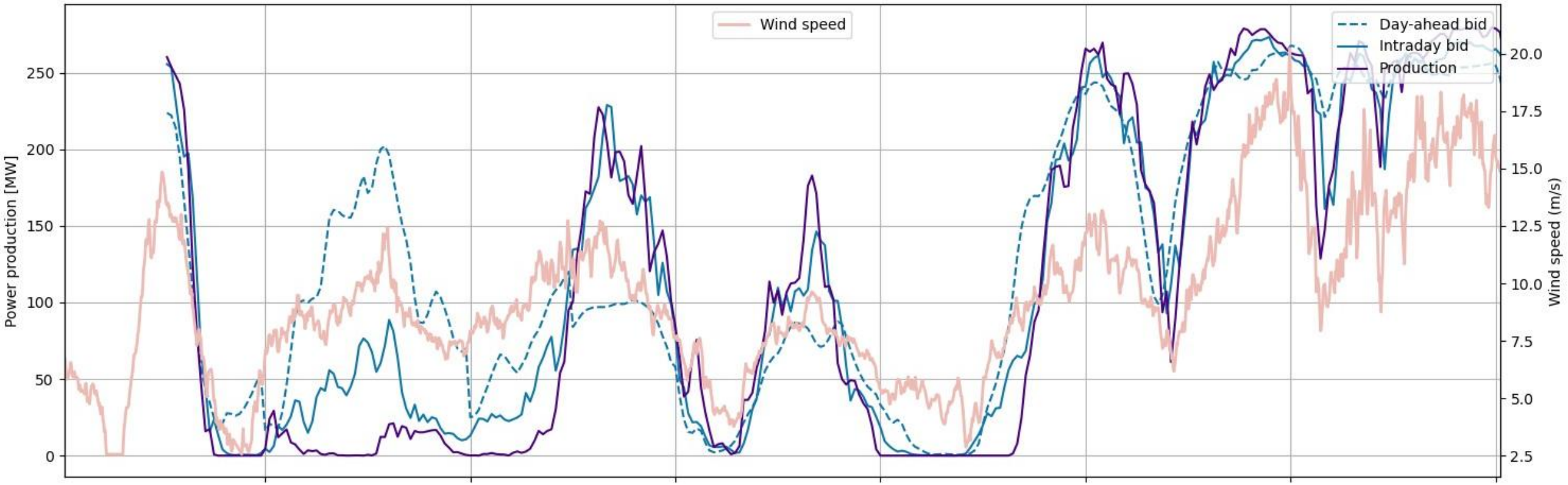




Understand the problem

Problem formulation

- Problem formulation
- Description of delivery
- Time horizon
- Precision
- Availability
- Granularity, spatial and temporal


Wind speed
Day-ahead bid
Intraday bid
Production
Power production [MW]
Wind speed (m/s)
0
50
100
150
200
250
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0

- Freezing water on wind turbines in winter
- Production is impacted
  - Imbalance
- The deficit must be bought back on intraday market
- Accurate forecasts of icing events reduces balancing costs



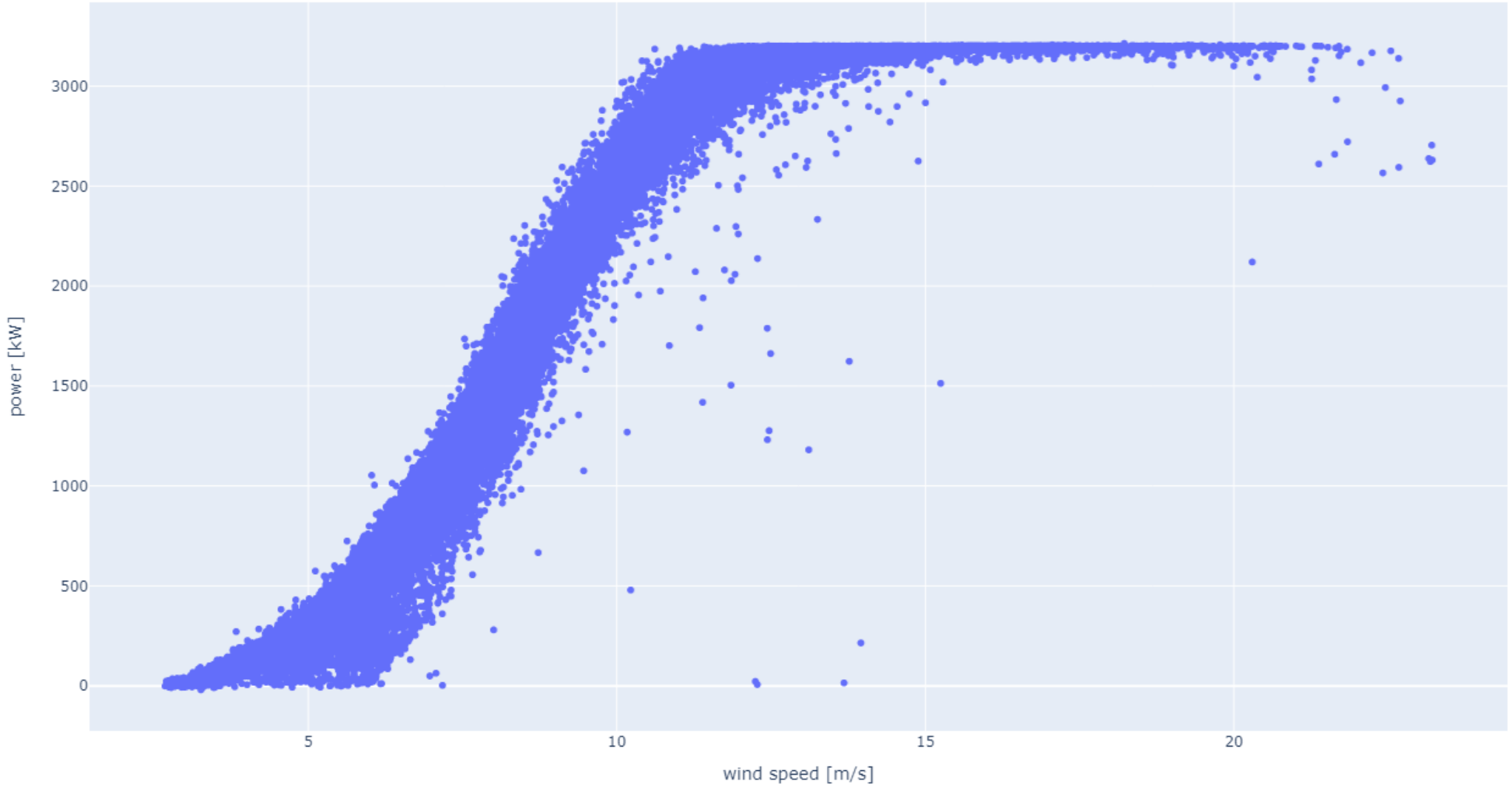
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Analyze historical data

- Which data are available internally?
- What do we need from external services?
- Data quality?
- Relevant forecast services?
- Dig into the data to see what we can learn from it



Statkraft

Understand the problem

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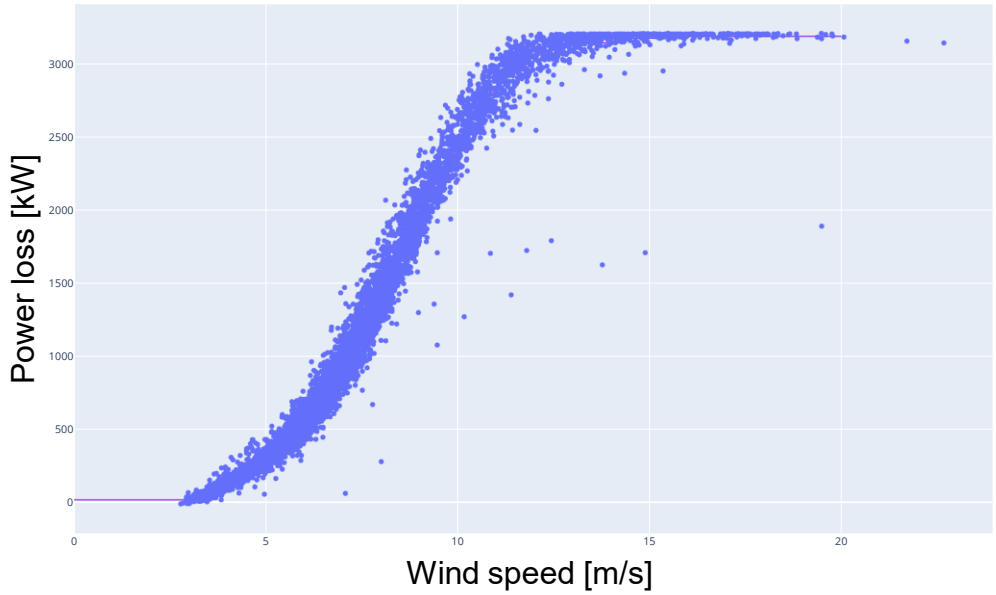
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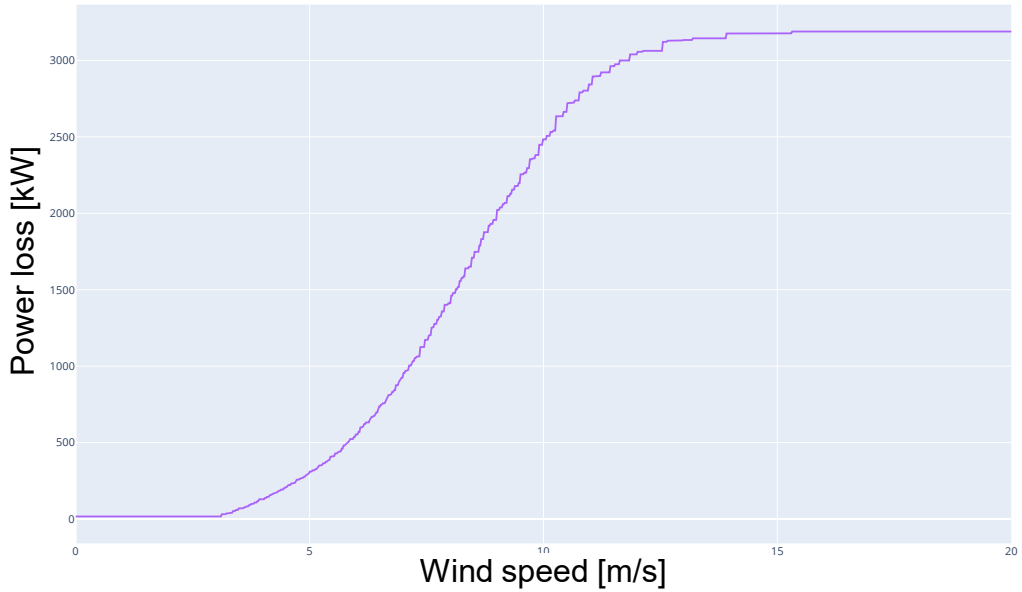
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Analysis of the problem

- Use relevant domain expertice, ask experts if needed.
- Literature review
- Do we need to develop other services before attack this problem?
- Do we have the necessary features in our data to build a service?

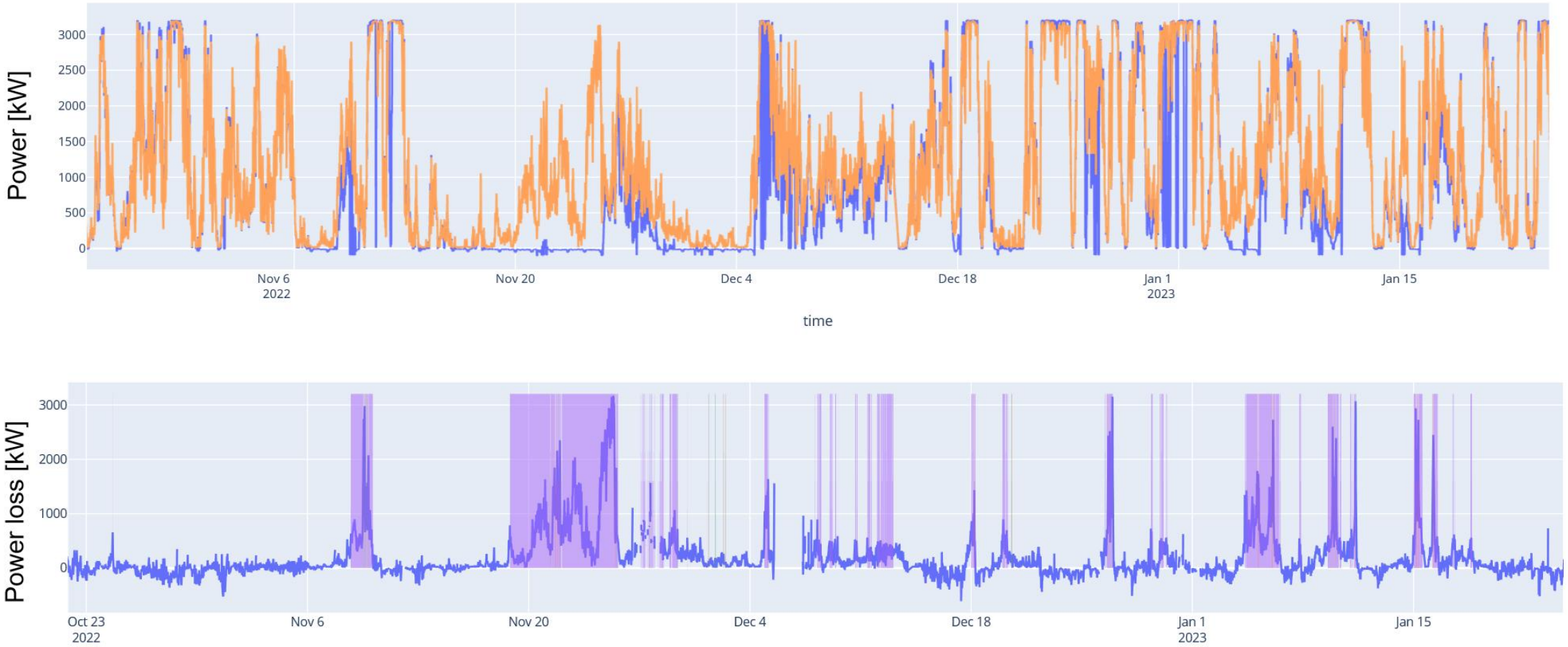
train model from data where we have no icing or any other operational issues





Statkraft

Estimate power loss



Statkraft

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Build a baseline model

- As simple as possible
- To be used for benchmarking more sophisticated methods

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Discuss the initial analysis and baseline with the customer

- Keep it simple
- Create many plots, but show only a few selected ones
- Focus on learning what creates most value for the customer


FARE FOR ISKAST
I kaldt vær kan isklumper falle eller kastes fra vindturbinene.
Det anbefales å holde en avstand på 200 meter til vindturbinene.
www.fosenvind.no
Fosen Vind

- Accumulated ice may be thrown off blades
- High quality icing forecast required
- Production does not matter, only if it is icing or not → Classification problem





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Find the right tool for the job

Develop a more sophisticated model

- Machine learning / optimization / physics model
- For ML, try out several
- Assess how the model scales
- benchmark against baseline

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- For ML, try out several
- Assess how the model scales
- benchmark against baseline

Go ahead with one model

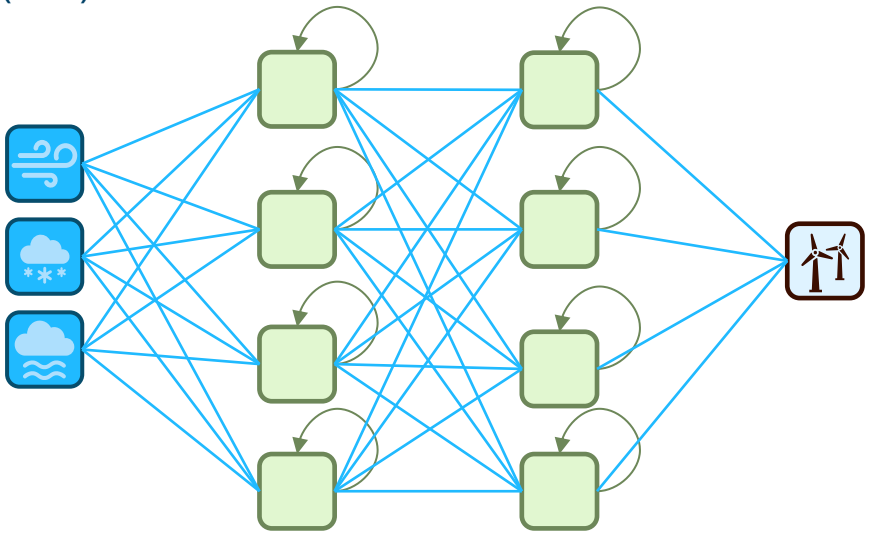
If ML:

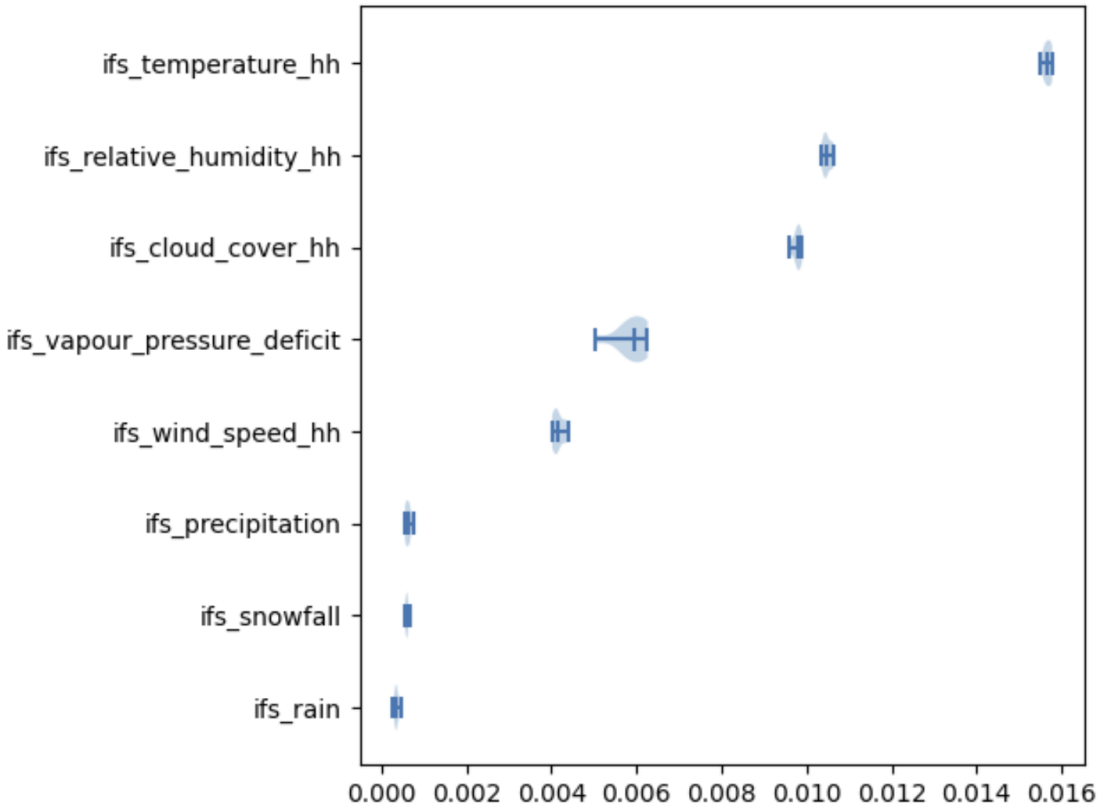
- model.fit()
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- Hyperparameter tuning
- Scaling

Weather forecast (IFS)

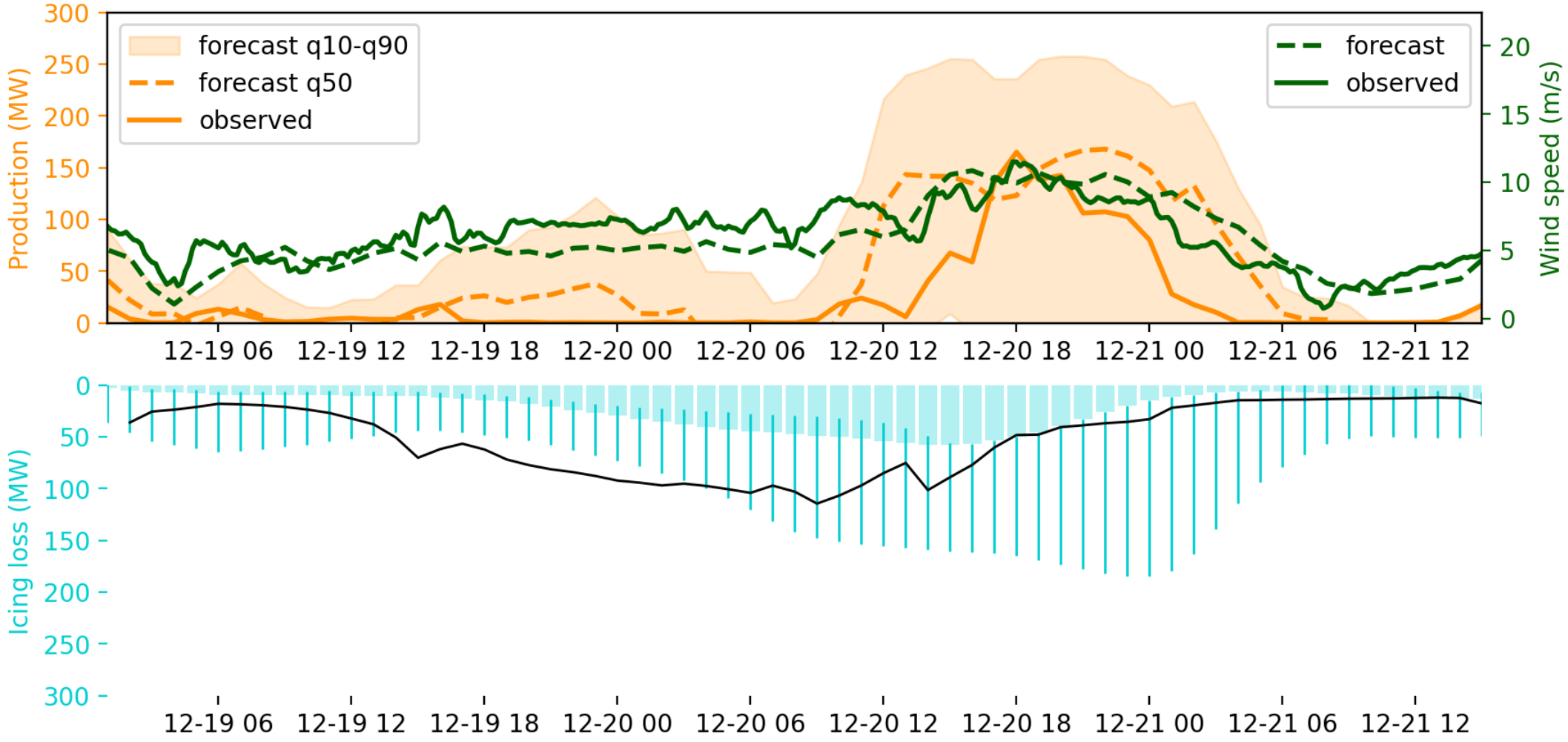
LSTM network

Power loss prediction





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forecast q10-q90
forecast q50
observed
forecast
observed
Production (MW)
Wind speed (m/s)
Icing loss (MW)
300
250
200
150
100
50
0
20
15
10
5
0
12-19 06
12-19 12
12-19 18
12-20 00
12-20 06
12-20 12
12-20 18
12-21 00
12-21 06
12-21 12

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Understand the problem

Problem formulation

- Problem formulation
- Description of delivery
- Time horizon
- Precision
- Availability
- Granularity, spatial and temporal

Analyze historical data

- Which data are available internally?
- What do we need from external services?
- Data quality?
- Relevant forecast services?
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Analysis of the problem

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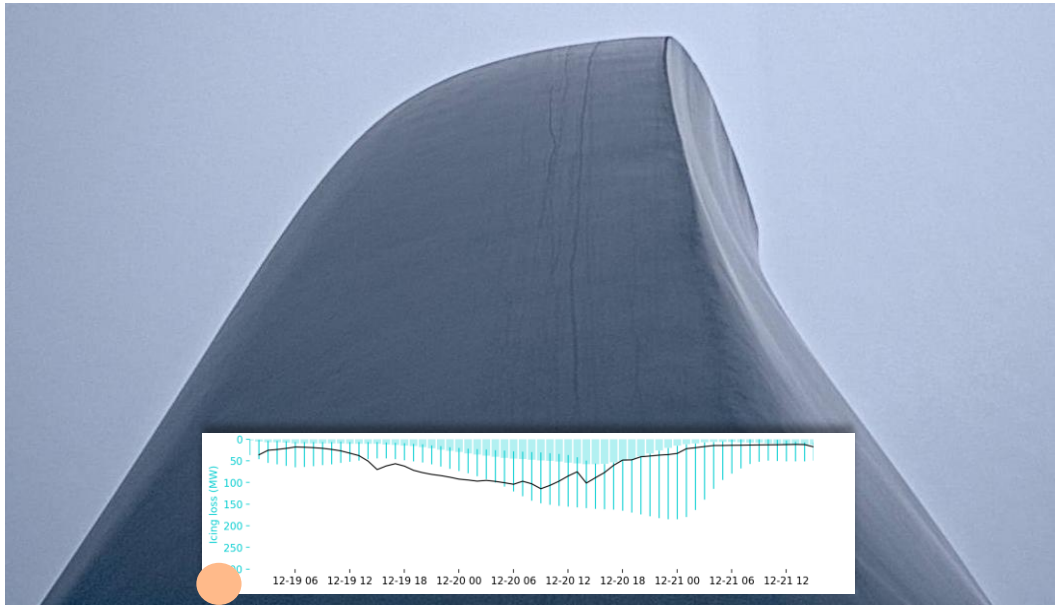
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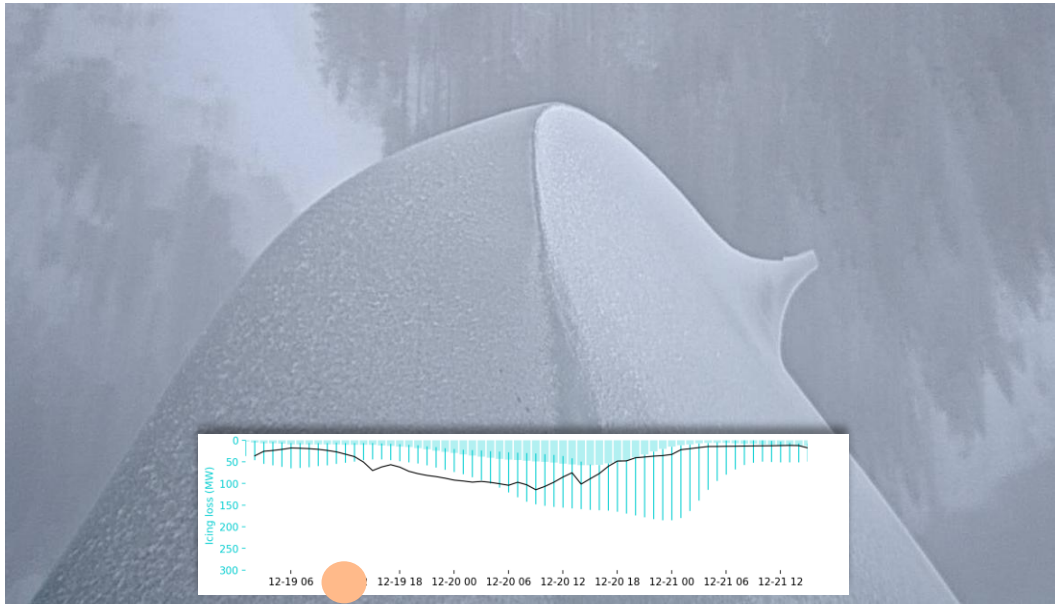
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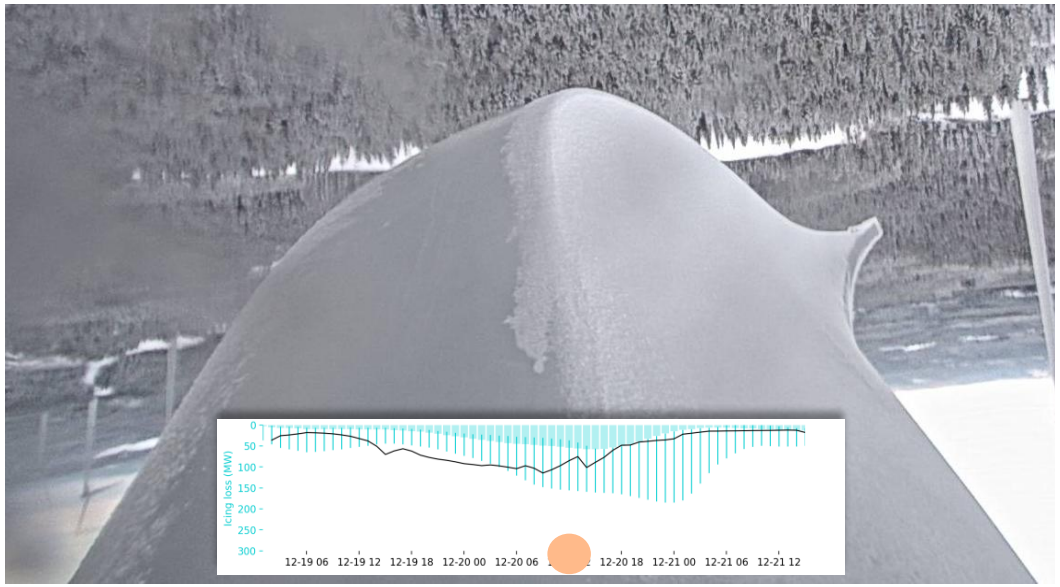
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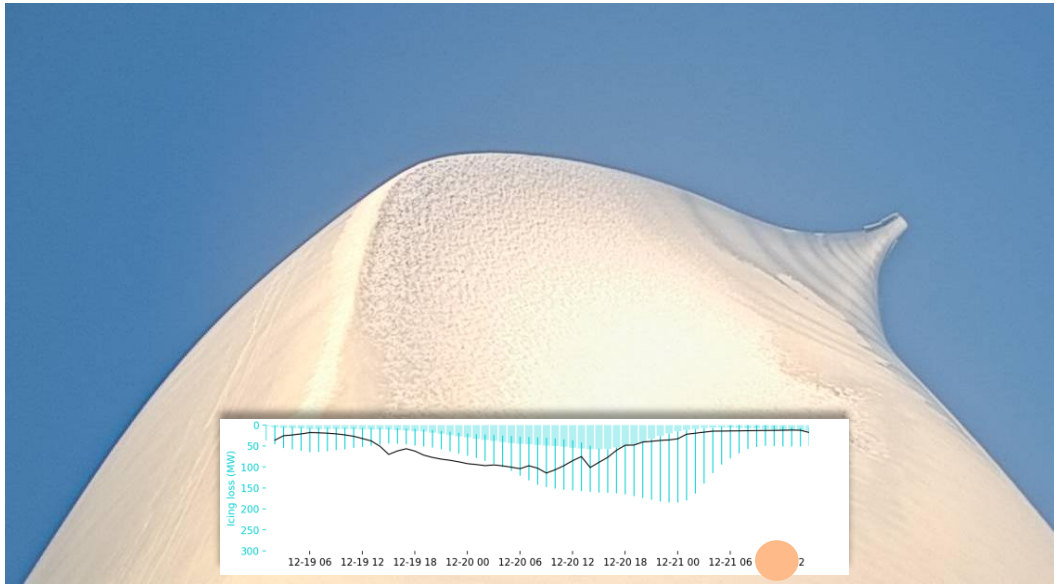
Validate

- Performance vs baseline
- Understand limitations of the model
- Depending on the model, more validation steps might be needed
- Test the model in staging in collaboration with customer


Icing loss (MW)
0
50
100
150
200
250
300
12-19 06
12-19 12
12-19 18
12-20 00
12-20 06
12-20 12
12-20 18
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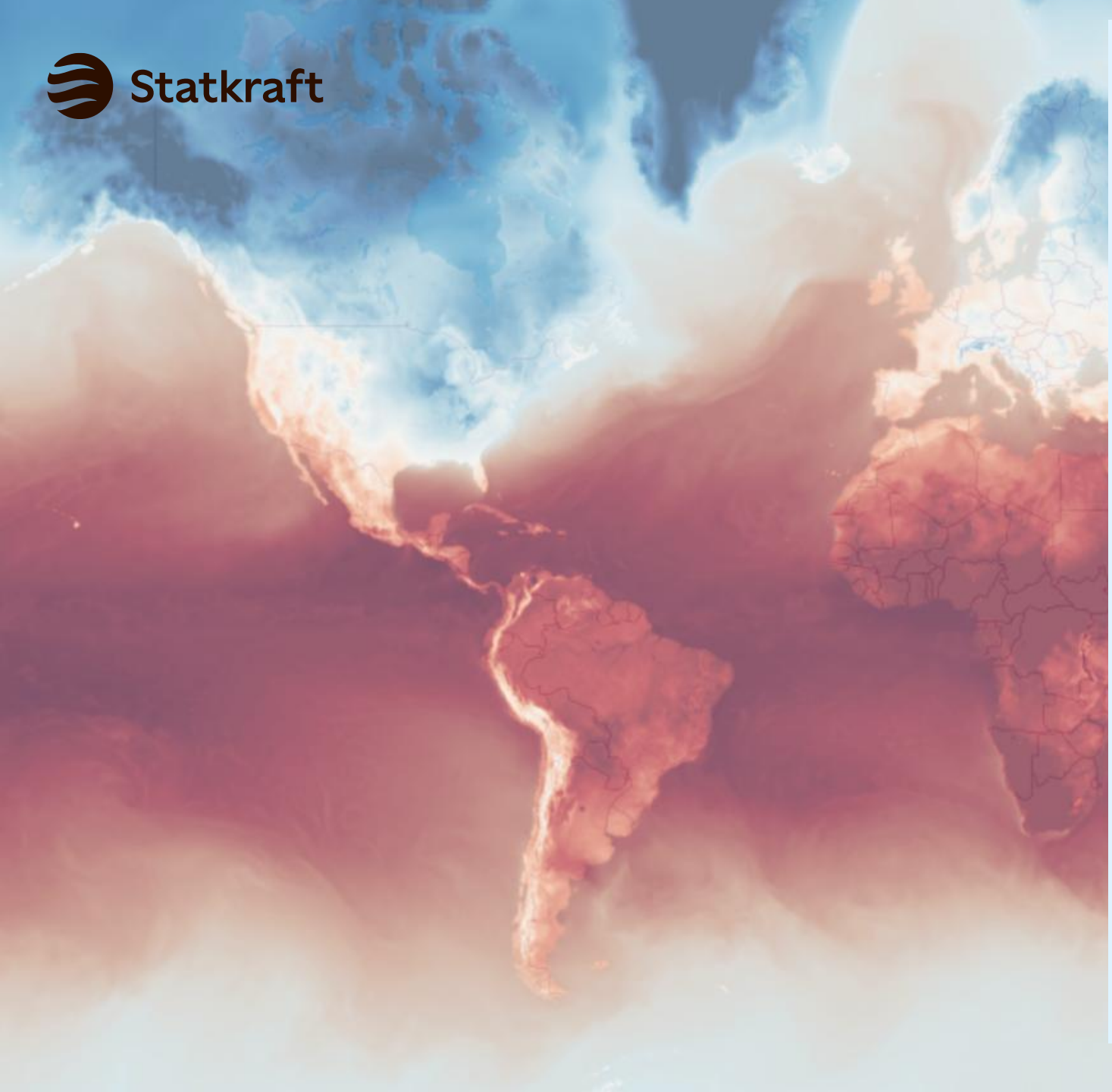
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Example of R&D project

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AI weather forecasts

- Very fast inference compared to physics based models
- Higher accuracy for many metrics
- Typically trained on reanalysis data (ERA5)
- Needs input state from physics based model

Next steps

- Foundation models for weather and climate
- Multiple input streams (reanalysis, satellite, observations)
- Custom decoder for specialized applications

Weather Generator

Advancing Earth system science with innovative AI



Project Overview

Learn about the aims and vision of the WeatherGenerator in this short animated video.

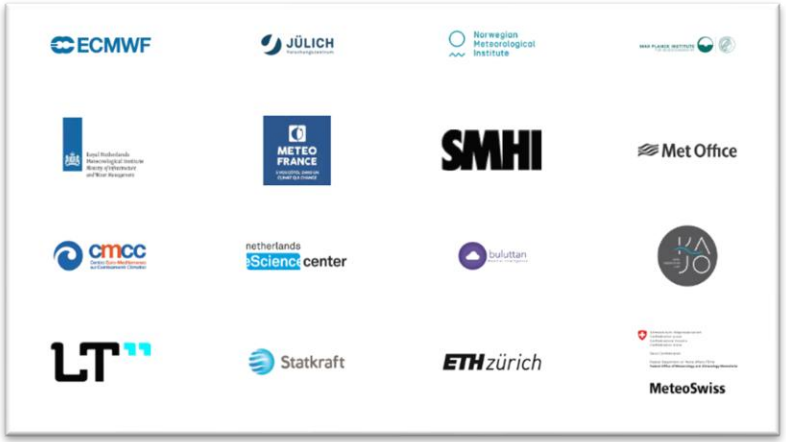
Groundbreaking European initiative aimed at transforming Earth system science through advanced AI and high-performance computing.

The WeatherGenerator's objective is to improve weather and climate predictions, enhance renewable energy planning, and provide better tools for mitigating the effect of extreme events like floods and heatwaves.

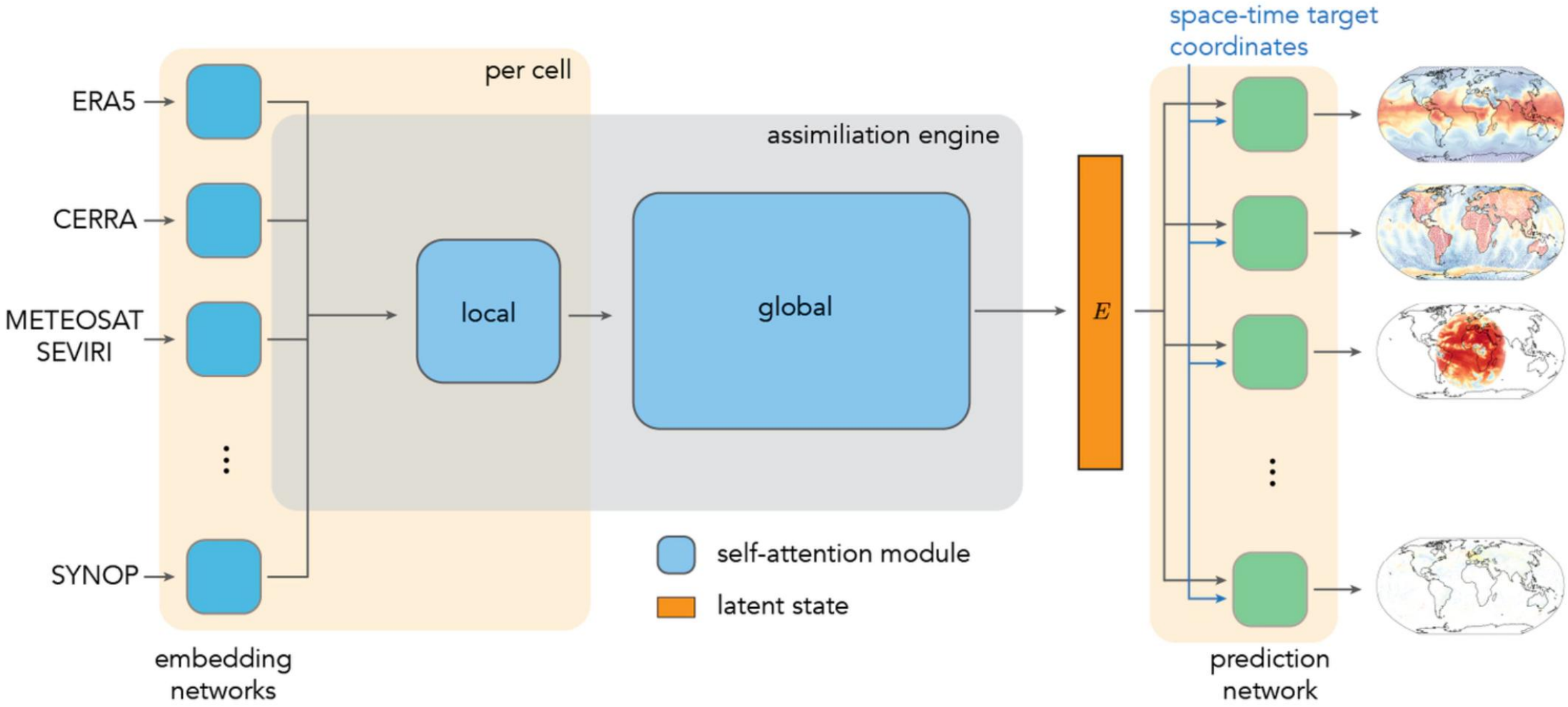
It will combine the latest machine learning with high performance computing, creating a robust tool for scientific discovery and real-world applications.

This way, the WeatherGenerator will ensure Europe remains at the forefront of innovation in weather and climate.

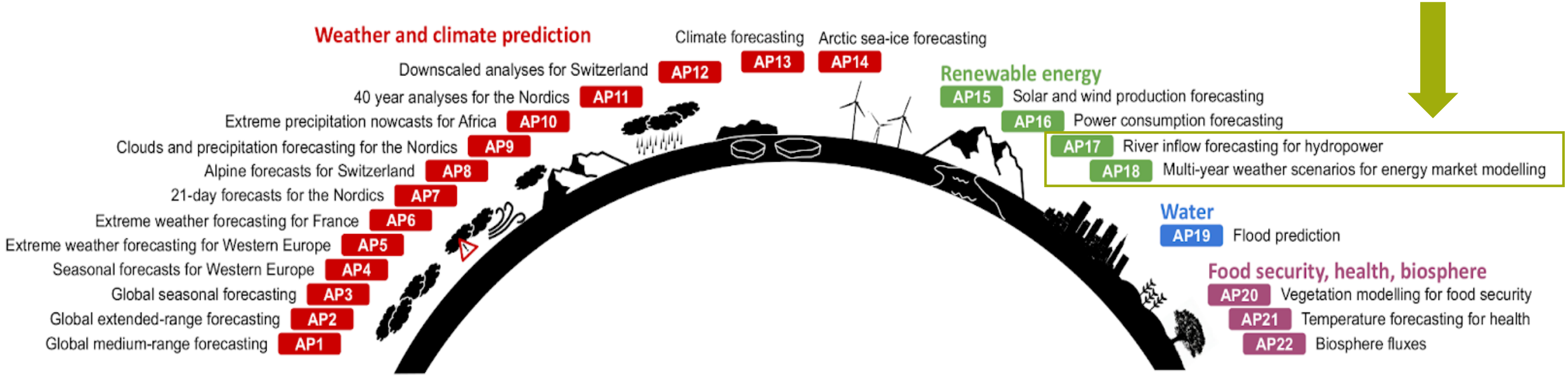
The resulting European foundation model will be accessible for multiple Earth system applications.



https://weathergenerator.eu/


space-time target coordinates
per cell
ERA5
CERRA
METEOSAT SEVIRI
SYNOP
assimiliation engine
local
global
E
self-attention module
latent state
embedding networks
prediction network

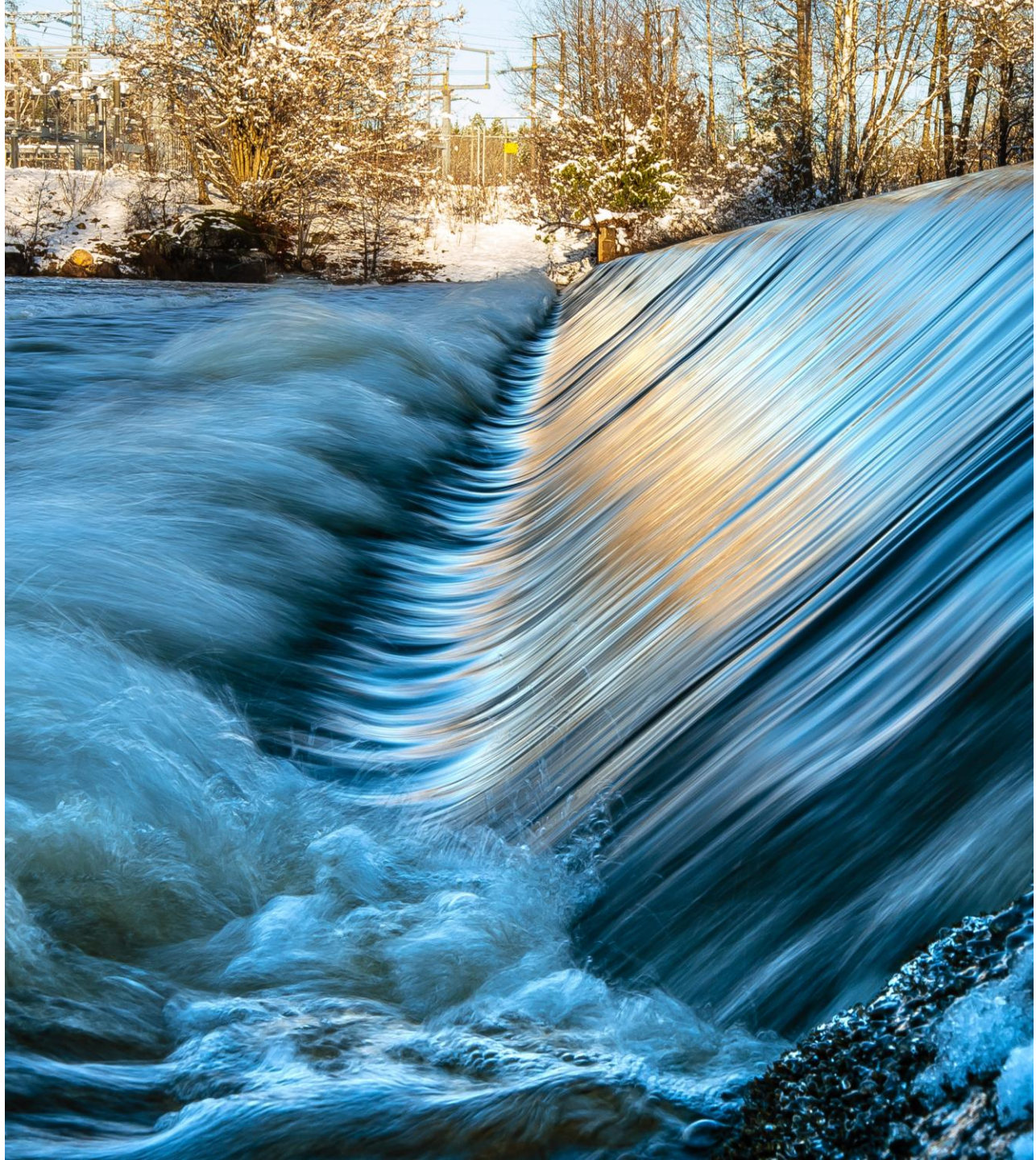
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Weather and climate prediction
Climate forecasting
Arctic sea-ice forecasting
Downscaled analyses for Switzerland AP12
AP13
AP14
40 year analyses for the Nordics AP11
Extreme precipitation nowcasts for Africa AP10
Clouds and precipitation forecasting for the Nordics AP9
Alpine forecasts for Switzerland AP8
21-day forecasts for the Nordics AP7
Extreme weather forecasting for France AP6
Extreme weather forecasting for Western Europe AP5
Seasonal forecasts for Western Europe AP4
Global seasonal forecasting AP3
Global extended-range forecasting AP2
Global medium-range forecasting AP1
Renewable energy
AP15 Solar and wind production forecasting
AP16 Power consumption forecasting
AP17 River inflow forecasting for hydropower
AP18 Multi-year weather scenarios for energy market modelling
Water
AP19 Flood prediction
Food security, health, biosphere
AP20 Vegetation modelling for food security
AP21 Temperature forecasting for health
AP22 Biosphere fluxes

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How could this affect power production forecasting?

- Latent space could be made available from forecast providers
- In-house forceasting becomes possible
- Weather forecast can be informed by our own measurements
- Custom decoders include the possibility of inflow and production forecasts fully integrated in the weather forecast



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Thank you

More info at statkraft.com