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Experiences of modelling icing and uncertainty estimations.

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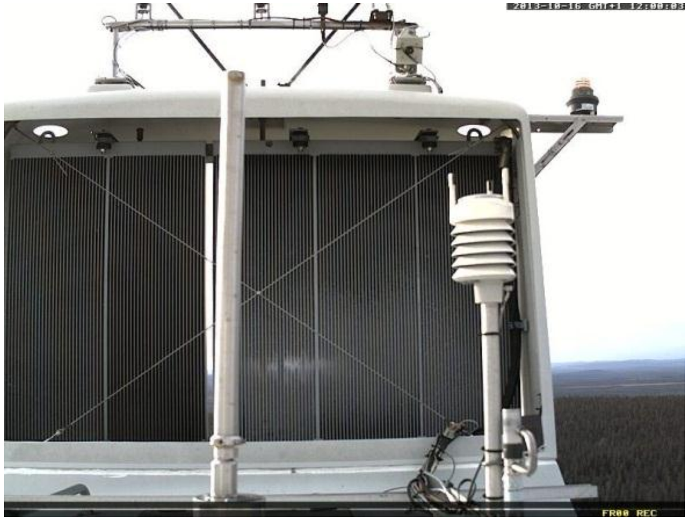
Measuring and modelling of ice load



Measuring ice load is not simple. Different techniques, but no one has proven to be totally reliable. Harsh environment.

"Results of the Vindforsk project V-363 with report "Experiences of different ice measurements methods" indicate that no technique and no instrument for measuring ice load or ice accretion can be trusted in every icing situation."

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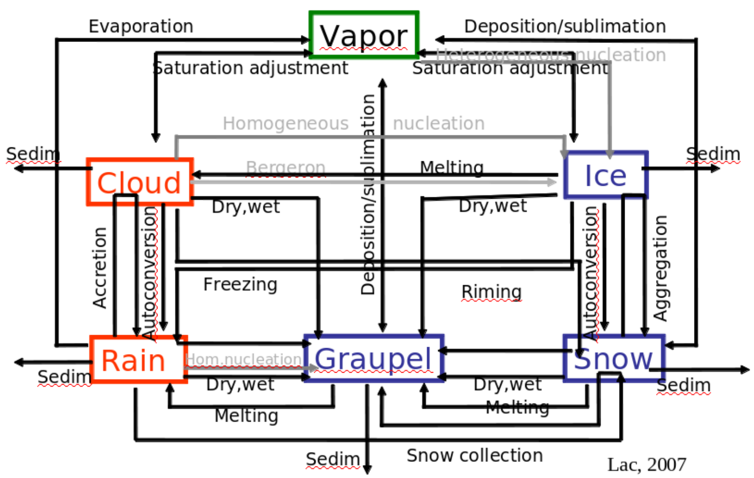
Measuring and modelling of ice load

- The state-of-the-art meso-scale weather models are able to simulate the time evolution of pressure, temperature, wind, and humidity quite accurately.
- The modelled ice load is calculated using wind speed, temperature and cloud condensates (Makkonen formula). Droplet concentration assumed to be constant.
- Experience so far shows that our models are able to capture the observed icing periods well in time.
- But there are often big differences seen between observed and modelled loads.
- Crude method for modelling ice shedding.
- How to treat mixed-phase clouds?

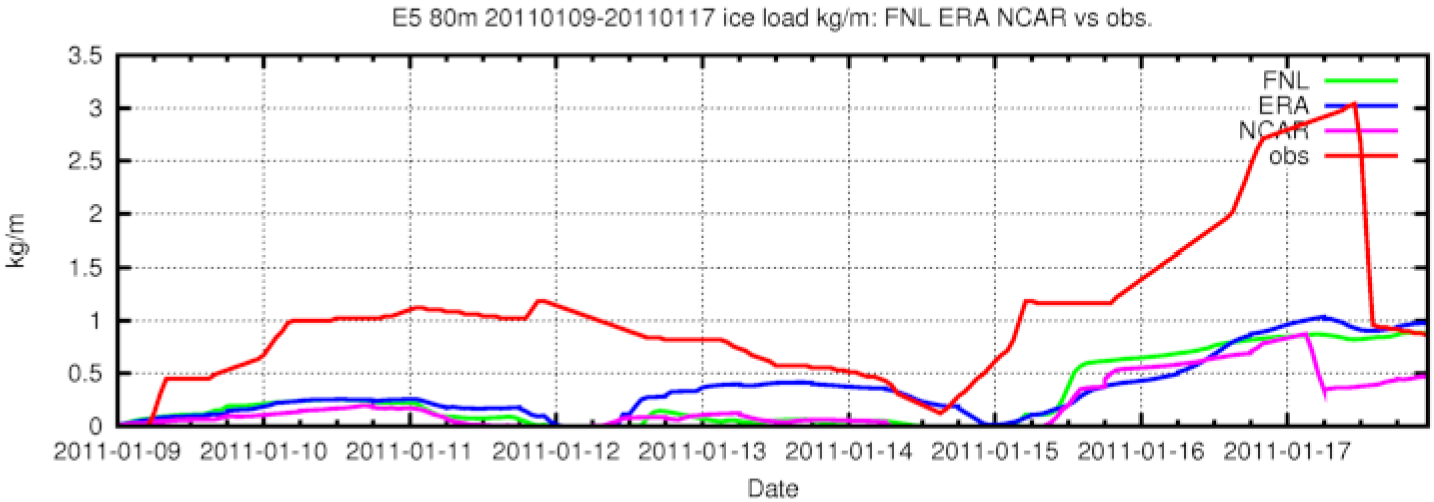
Model uncertainties



- Complex physical parameterizations needed to describe all small scale processes, e.g. a microphysical cloud scheme shown here.
- Different schemes applied in the models used.

- Initial conditions also very important.
- Small scale models also need good boundary conditions.

Model uncertainties



WRF-model ice load. Three different boundary conditions

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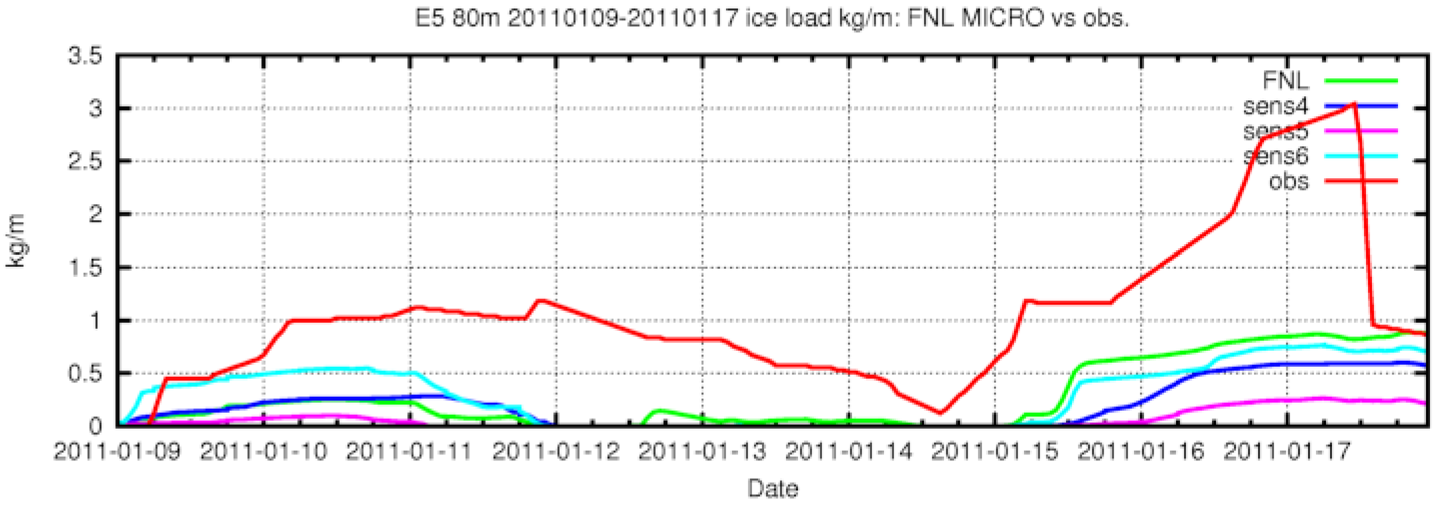
Model uncertainties



WRF-model ice load. Four different micro-physical schemes.

Model uncertainties

- Hard to relate ice load on a cylinder to power loss on a wind turbine.
- Statistical methods seems to be the way to go now.
- Observed power loss??

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Addressing model uncertainties; new project funded by Swedish Energy Agency.

- Title: Windpower in cold climate - modelling of icing and production losses. 2014-2016.
- Uppsala University, Weathertech Scandinavia AB, SMHI and Vattenfall Vindkraft AB.
- Goals:
  - ✓ Refine the meteorological methods to calculate ice load and production losses.
  - ✓ Quantify uncertainties in icing calculations.
  - ✓ Ensemble model techniques will used.

- A PhD student will be recruited.

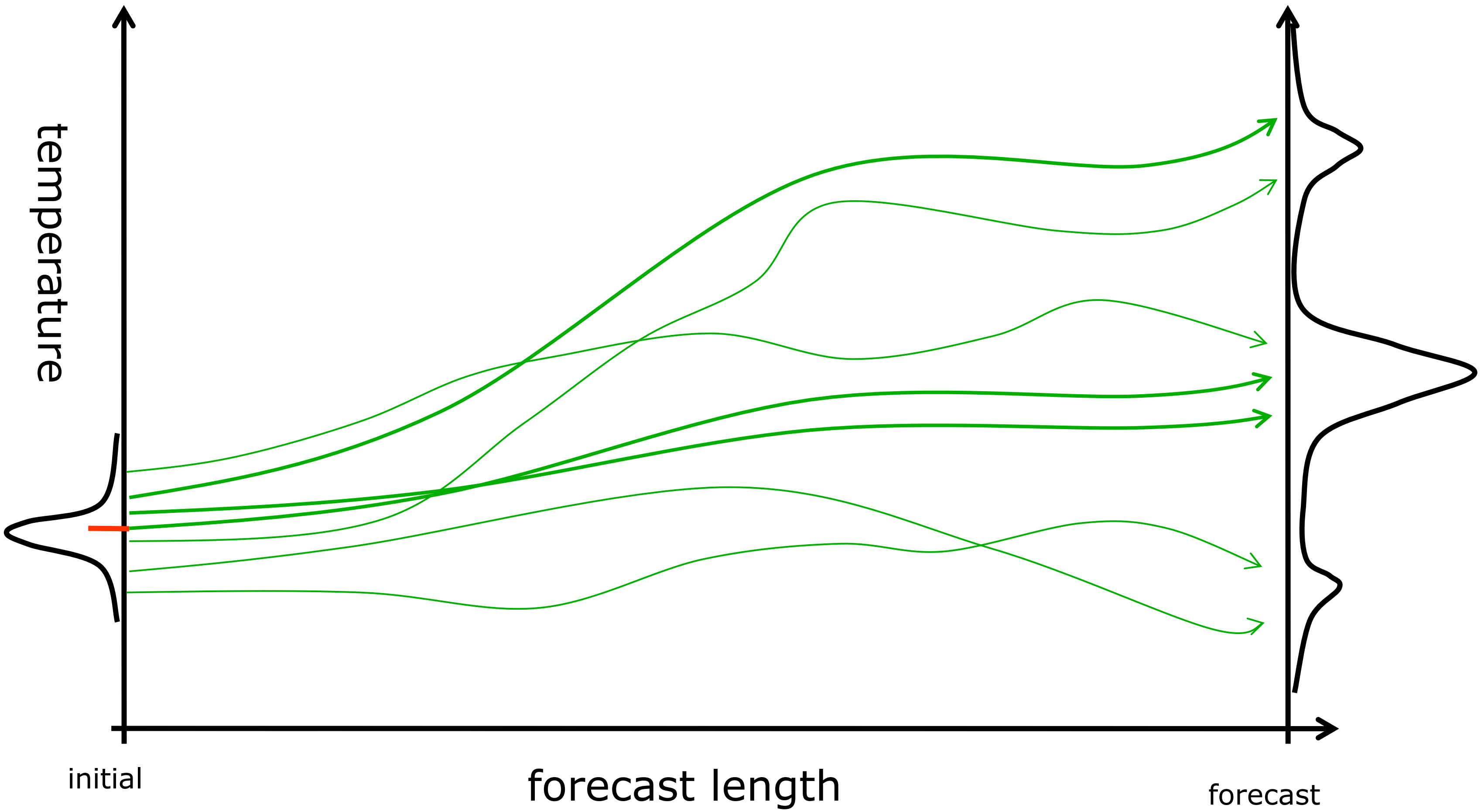
Ensemble Prediction Systems (EPS) in general

- Errors in numerical weather predictions are caused by:
  - ✓ All atmospheric processes can not be modelled accurately enough.
  - ✓ There are errors in the initial conditions (not enough observations).

- EPS addresses this by running a lot of forecasts;
  - ✓ Perturbing the initial state
  - ✓ Introducing perturbations into the model physics (small scale processes).

- Probabilistic forecasts.

Ensemble Prediction Systems (EPS) in general

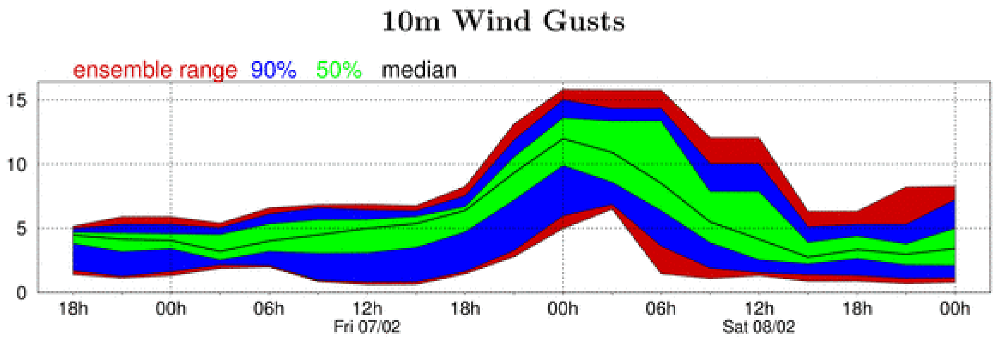


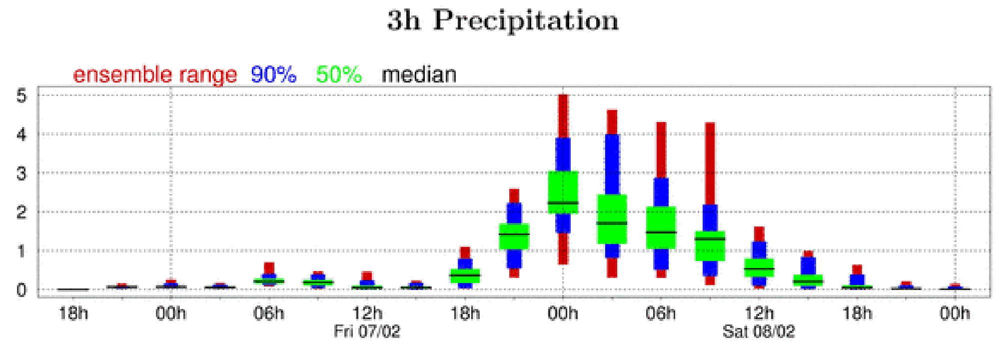
The weather development as a
Probability Density Function (PDF)

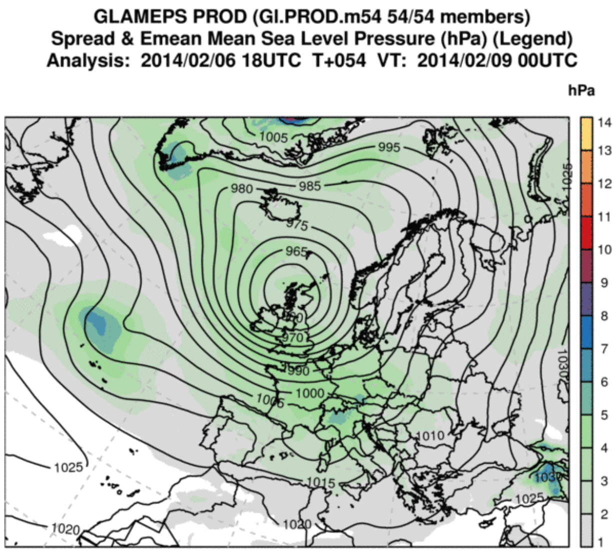
High resolution EPS

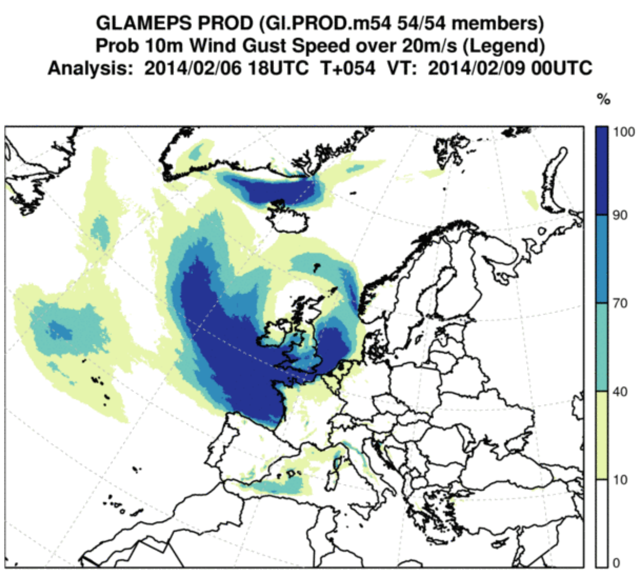
- GLAMEPS
  - ✓ Grand Limited Area Model Ensemble Prediction System
  - ✓ Hirlam and Aladin model consortia.
  - ✓ High resolution and limited-area ensemble forecasting for European territory.
  - ✓ Forecasts up to 2 days ahead, with grid resolution at about 12 km, produced twice per day (06 and 18 UTC).
  - ✓ 54 members.
  - ✓ Run at ECMWF, semi-operational.

High resolution EPS









High resolution EPS

- HarmonEPS
  - ✓ Hirlam and Aladin model consortia.
  - ✓ Highest possible resolution.
  - ✓ Forecasts up to 36 hours, with grid resolution at about 2.5 km.
  - ✓ Arome and Alaro physics, 20 (10+10) members + 2 ctrl.
  - ✓ Focus on extreme precipitation and high wind speed events.
  - ✓ Still experimental.
  - ✓ Now tested in Sochi.

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Ensemble predictions of ice load and production losses

- The new project will focus on:
  - ✓ Implementing latest developments in model physics.
  - ✓ Refining ice load calculations:
    - Topographical adjustment.
    - Ice throw.
    - Sublimation.
    - Mixed phase clouds / precipitation.
  - ✓ Statistical methods for estimating power production losses.

Ensemble predictions of ice load and production losses

- Introducing EPS will provide means to:

  - ✓ Quantify uncertainties in ice load calculations.

  - ✓ Use a probabilistic approach for power loss estimations.

High resolution climatologies under development.

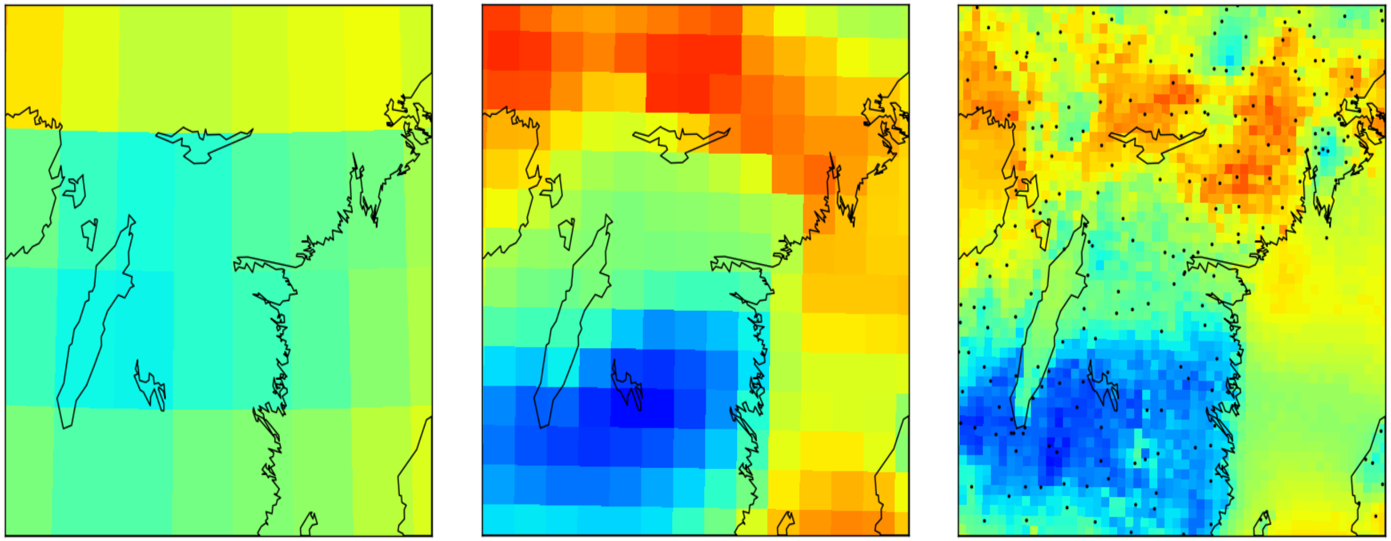
- Reconstruction of historical weather in European projects:
  - ✓ EURO4M (1981-2010), finished in March 2014
  - ✓ UERRA (1961-2013), finished in 2017

High resolution reanalysis provides a unique opportunity for mapping of icing and wind climatology using downscaling.

High resolution climatologies under development.

2m-temperature in

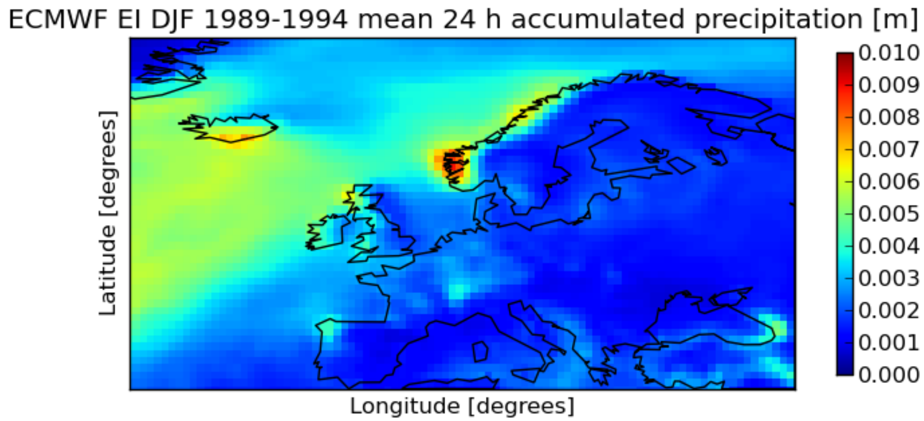
ERA-Interim HIRLAM 22 (11) km MESAN 2D 5km

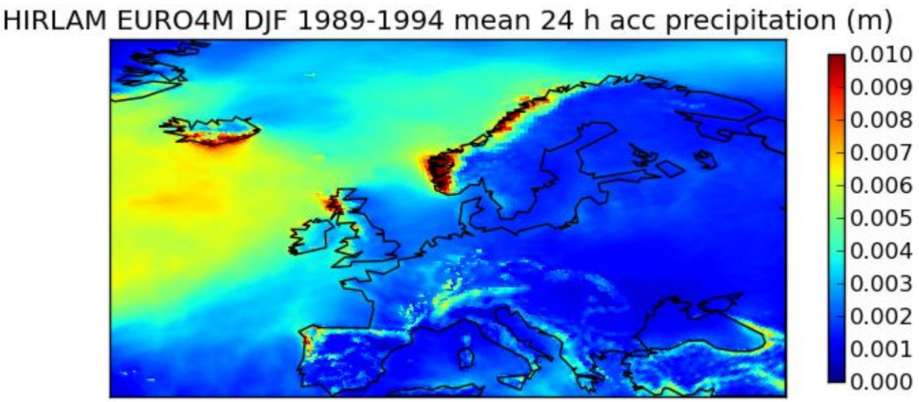


High resolution climatologies under development.

Climatological precipitation

ERA-interim DJF HIRLAM-EURO4M





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Summary

- A new project funded by Swedish Energy Agency has started.
- Ice load and wind power production loss calculations will be improved.
- Ensemble forecast techniques will be used to quantify uncertainties.