CES Nordic Project on Climate and Energy Systems

norden Nordic Energy Research

RD&D Needs for Energy Systems Preparedness and Resilience, Utrecht, the Netherlands, 13-14 November 2013

Climate change impacts on renewable energy sources in the Nordic and Baltic countries until 2050

Presentation based on input from working groups led by:

**Árni Snorrason, Birger Mo, Deborah Lawrence,
Erik Kjellström, Jari Schabel, Niels-Erik Clausen,
Seppo Kellimäki, Sten Bergström, Tómas Jóhannesson
& co-authors and the editor Þorsteinn Þorsteinsson**

Presented by: Árni Snorrason
Icelandic Meteorological Office

The Nordic Project *Climate and Energy Systems*

- **One of 16 projects selected to form part of Nordic Energy Research´s 2007-2010 strategy and action plan.**
- **Objective: To improve the decision framework of the energy sector with regard to climate change impact on renewable energy resources and the energy system**
- **30+ partners from the 5 Nordic + the Baltic countries**
- **Focus on hydropower, wind energy and biomass**
- **Supported by Nordic Energy Research and the Nordic Energy Industry (DONG Energy Denmark, Statkraft Norway, Elforsk Sweden, the Finnish Energy Industries and the National Power Company, Iceland)**

Veðurstofa Íslands

Nordic-Baltic projects on the impact of climate change on renewable energy

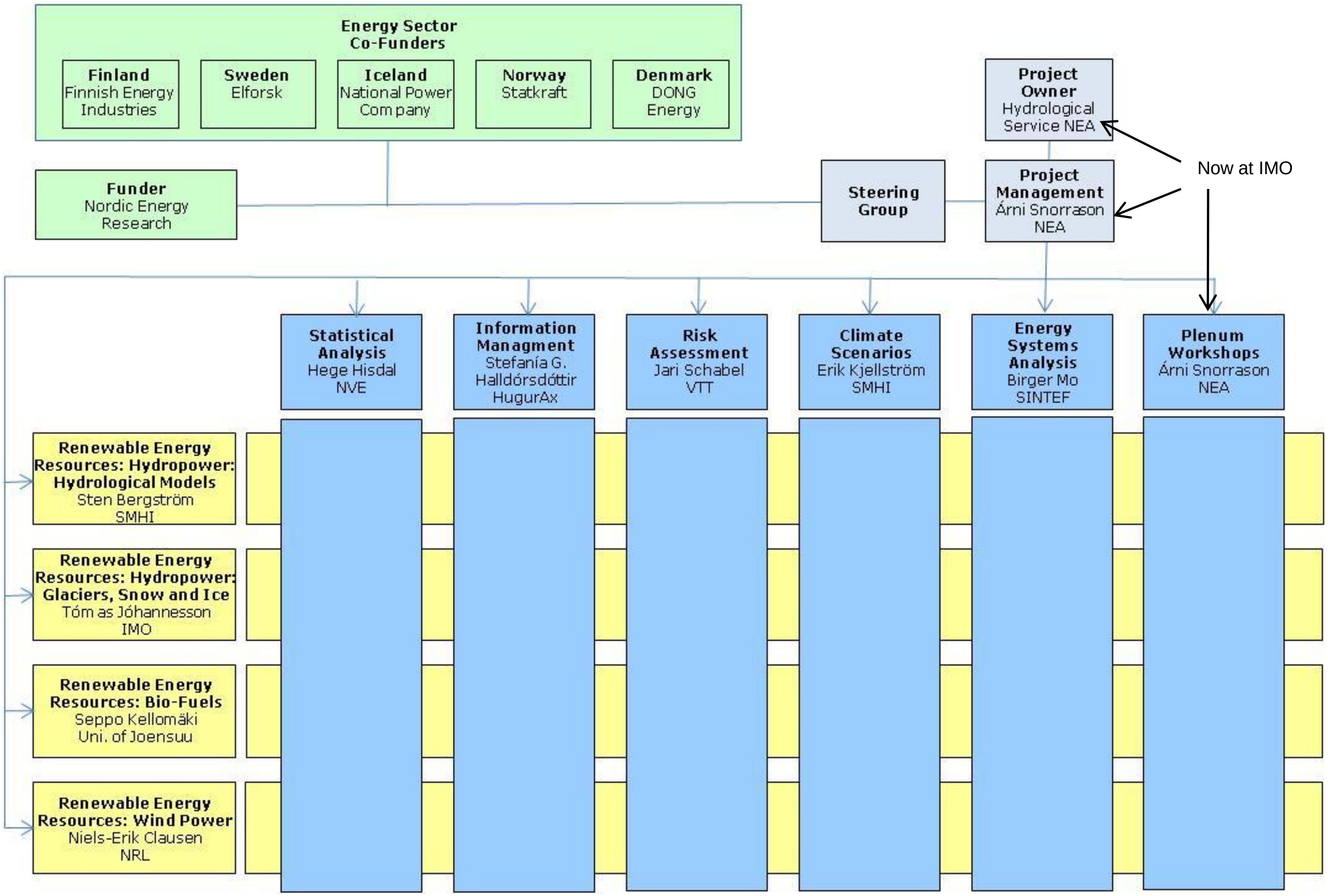
Climate Water and Energy 2001-2002 (2MNOK)

Climate and Energy 2003-2006 (15MNOK)

Climate and Energy Systems 2007-2010 (18MNOK)

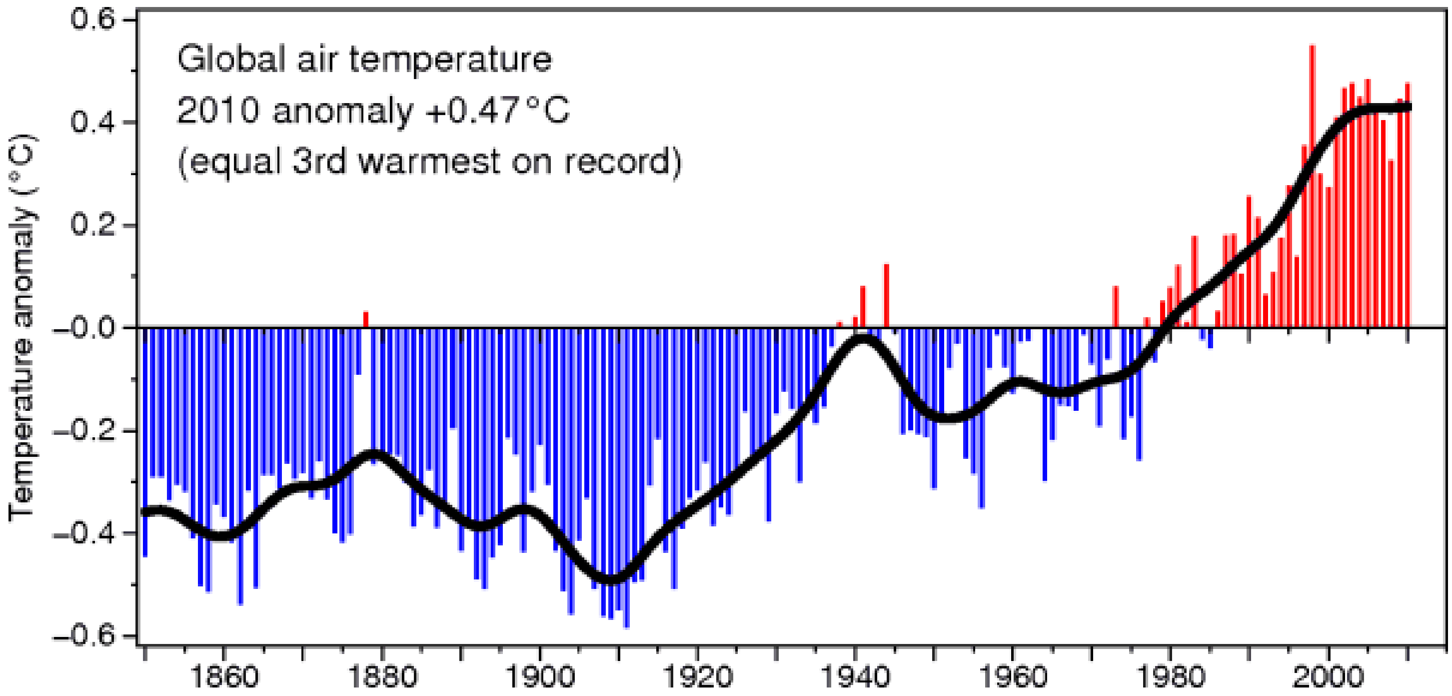
Funded by Nordic Energy Research and the partners

Partners, organisation



The climate system: A brief update

CRU, University of East Anglia



2010 and 2003 equal third warmest on record.
Surpassed only by 1998 and 2005.
CRU: 2001-2010 was 0.44°C warmer than 1961-1990 and 0.20°C warmer than 1991-2000.

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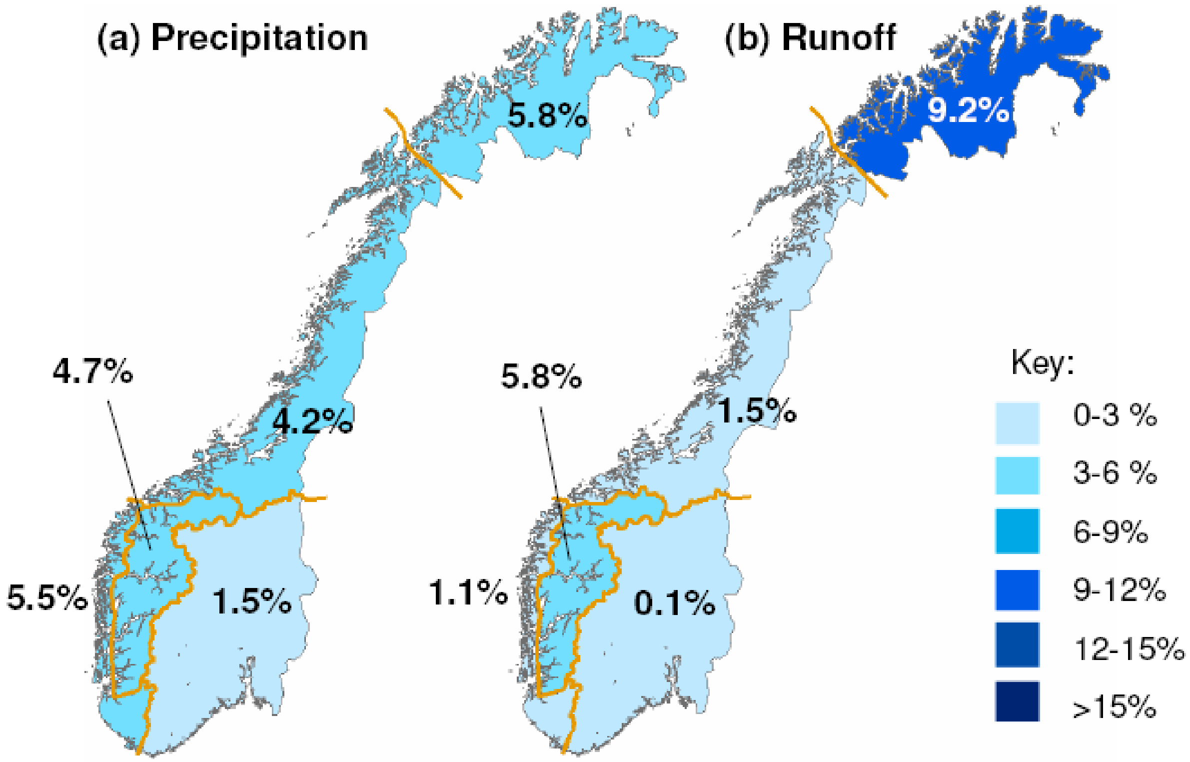
Statistical analysis group

Sets the scene for future climate scenarios through studies of patterns of change in historical data

PI: Deborah Lawrence, Norges Vassdrags og Energidirektorat (NVE)

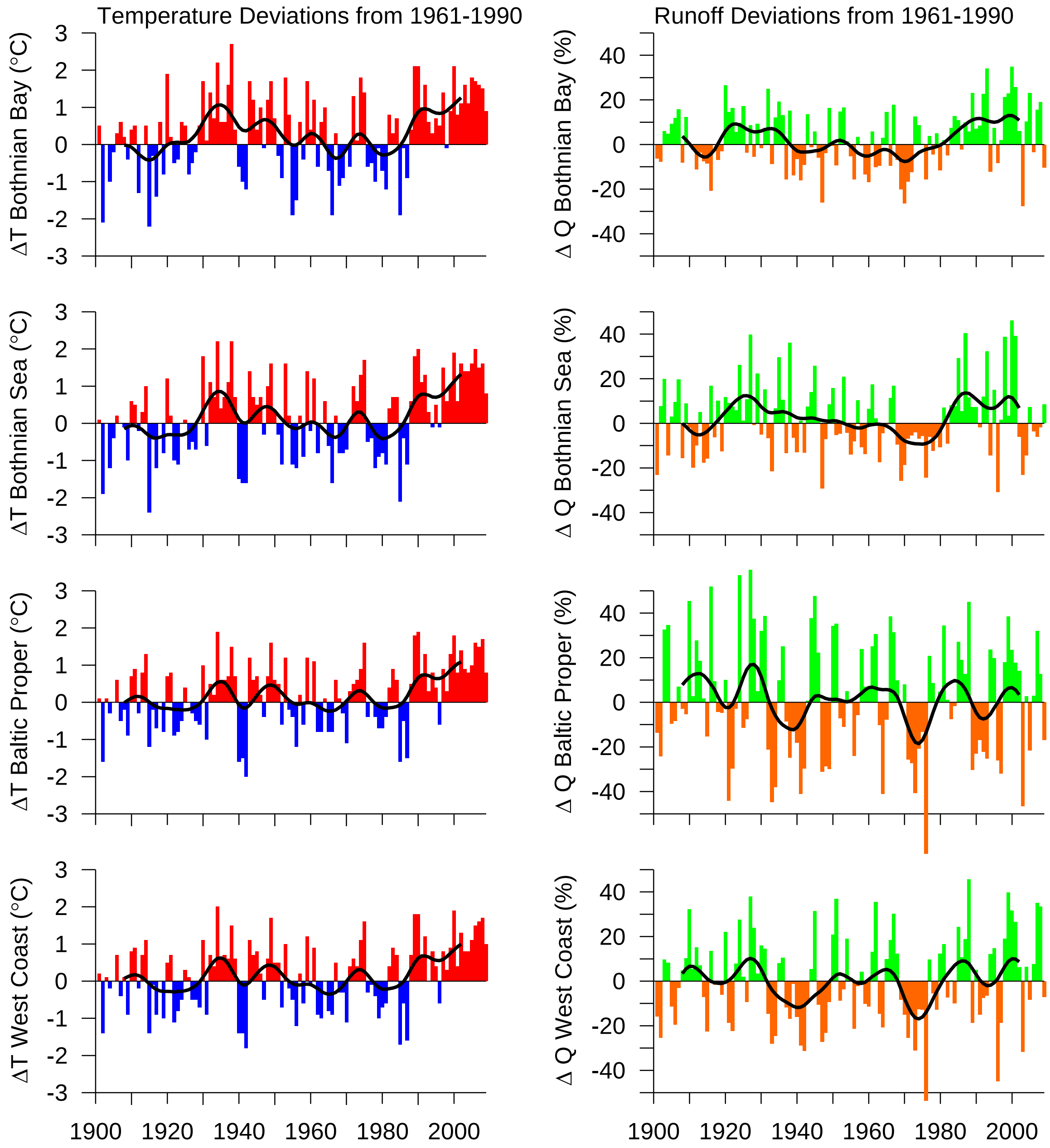
- **Analyses of regional series and trends in climate parameters and streamflow/runoff for the individual countries**
- **Analyses of changes in the occurrence of extreme events**
- **Analyses of links between atmospheric processes and local variables of interest to the energy sector; i.e. streamflow and wind**

Statistical analysis: Example from Norway



Percentage increase in regional precipitation and runoff in the period 1990–2003, relative to the 1961–1990 reference period.

Time series of temperature and runoff from Sweden 1901-2009



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The Climate Modelling and Scenarios Group

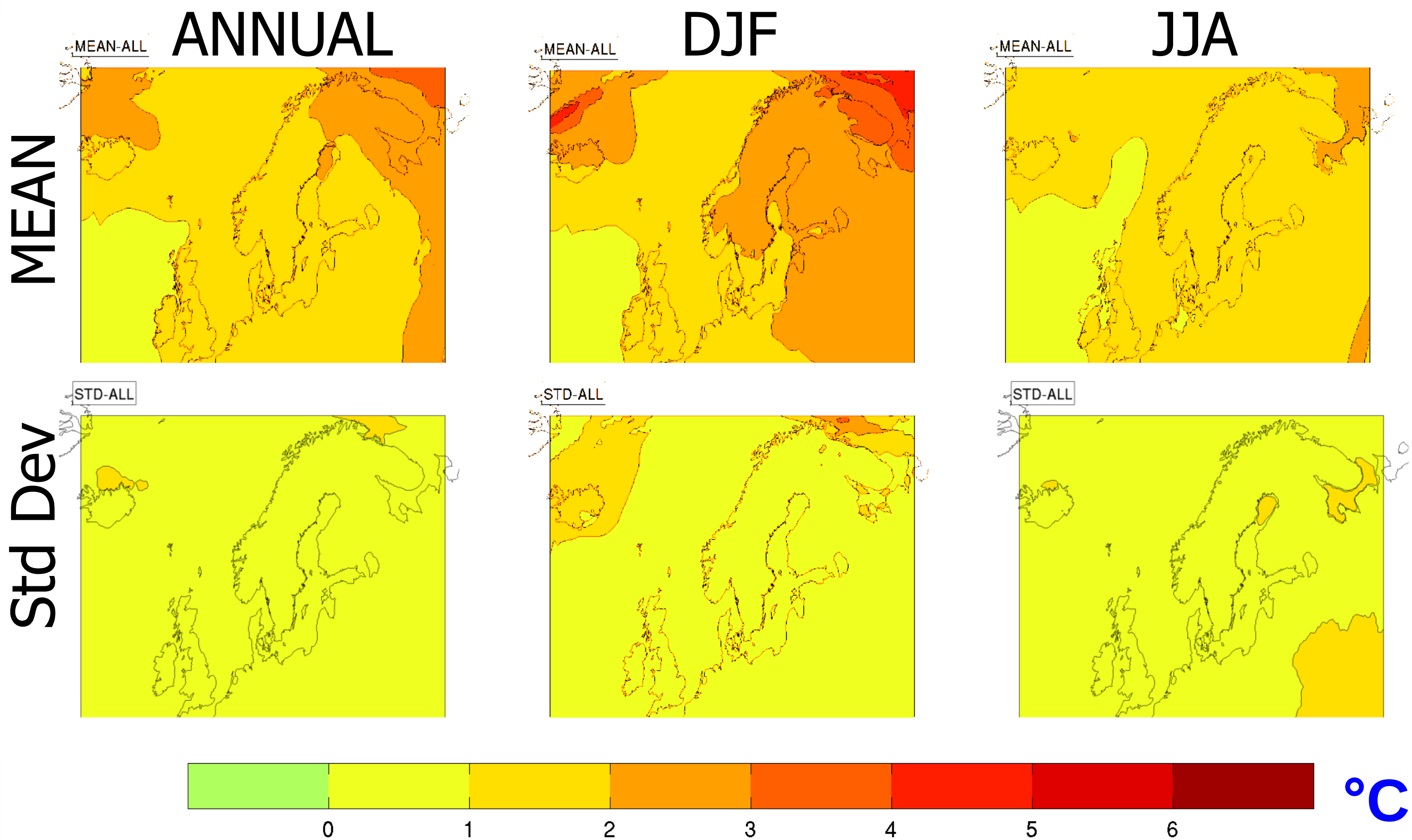
Used output from global Atmosphere Ocean General Circulation Models (AOGCMs) to forecast future climate of the Nordic region

PI: Erik Kjellström, Sveriges Meteorologiska och Hydrologiska Institut (SMHI)

- **Provided regional climate scenarios at 25 km resolution for the CES groups**
- **High-resolution climate change scenarios at 1-3 km horizontal resolution for selected areas**
- **Evaluated the range and probabilities of modelled mean climate and climate variability, for the period 2010-2050**
- **Analysed regional climate scenarios in terms of impact-relevant indices**

Regional climate change simulations: ensemble mean

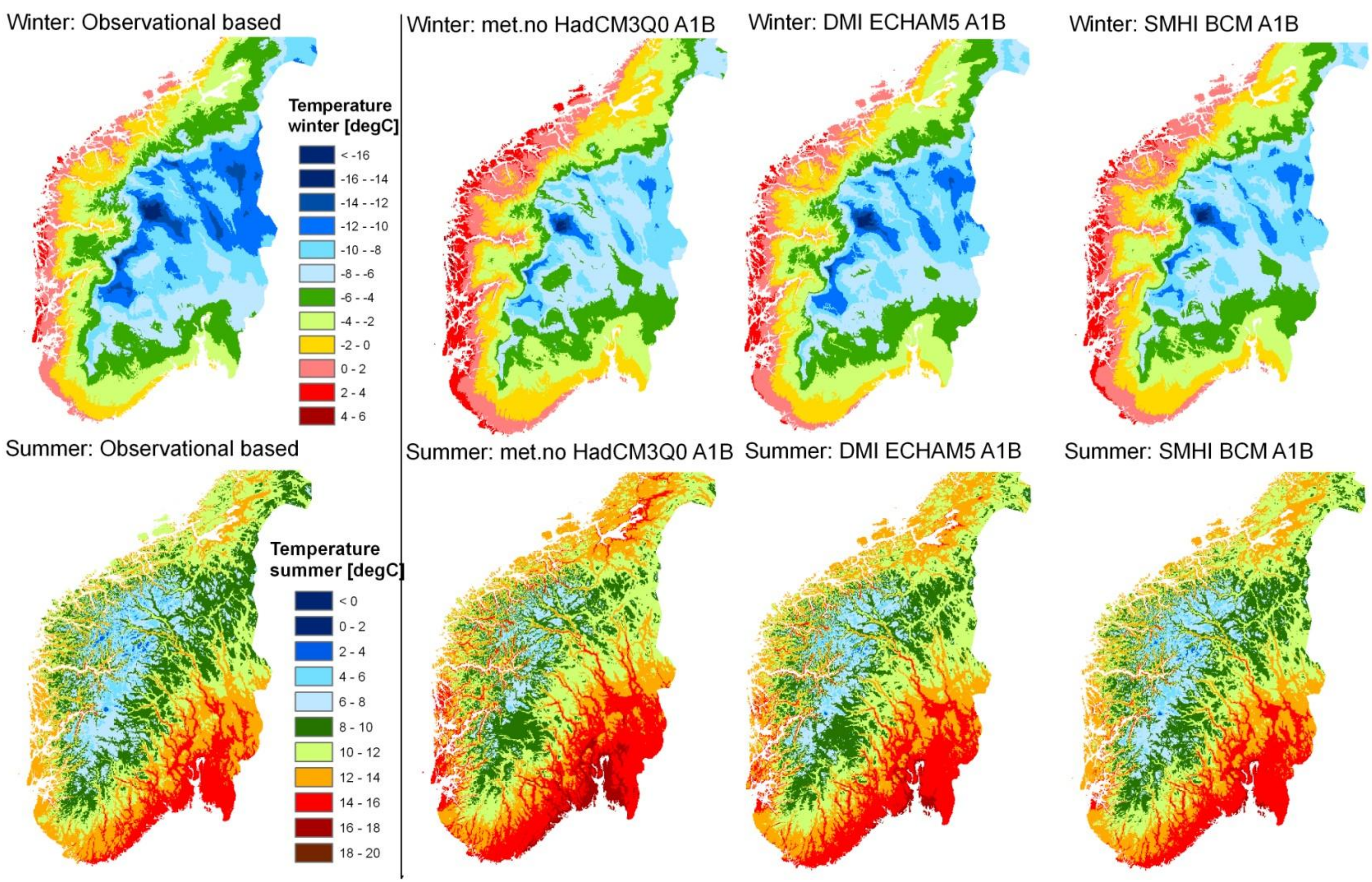
15-member ensemble mean change (2021-2050 vs 1961-1990) in T2m



Downscaling of RCM output to 1km horizontal resolution by a statistical method

Projections of temperature for southern Norway for 2021-2050 as compared with 1961-1990.

Observed **Projected**



Hydropower, snow and ice group

Used the climate scenarios along with extensive data sets on glacier mass balance in Scandinavia and Iceland to model future changes in glacier volume and meltwater delivery from glaciers

PI: Tómas Jóhannesson, Veðurstofu Íslands (Icelandic Meteorological Office, IMO)

- **Mass balance and dynamic modelling of glaciers in Iceland, Norway and Sweden**
- **Precipitation downscaling in Iceland and Scandinavia**
- **Coupled glacial runoff – dynamic glacier modelling in Iceland and Norway**
- **Meteorological downscaling and mass balance modelling of a glacierized watershed in Greenland**

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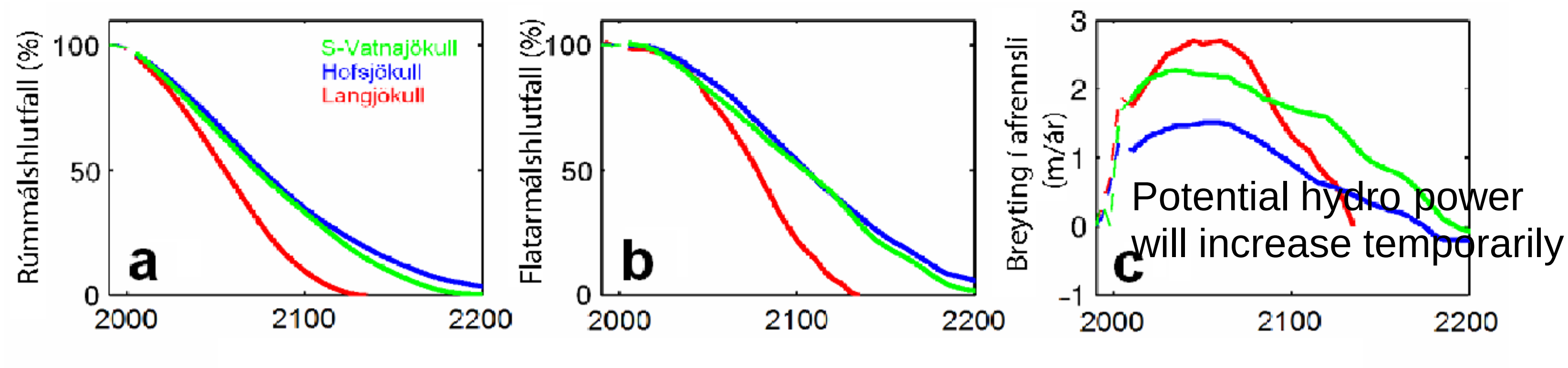
Some conclusions from the snow and ice group

- **Many glaciers and ice caps, except the Greenland ice sheet, are projected to disappear in 100-200 years.**
- **Runoff from ice-covered areas in the period 2020-2051 may increase by on the order of 50% with respect to the 1961-1990 baseline**
- **There will be large changes in runoff seasonality and in the diurnal runoff cycle**
- **The runoff change may be important for the design and operation of hydroelectric power plants and other utilisation of water**
- **There is a large uncertainty associated with differences between the modelled climate development by different GCMs and RCMs**

Runoff changes:examples from Iceland

Icelandic Met Office



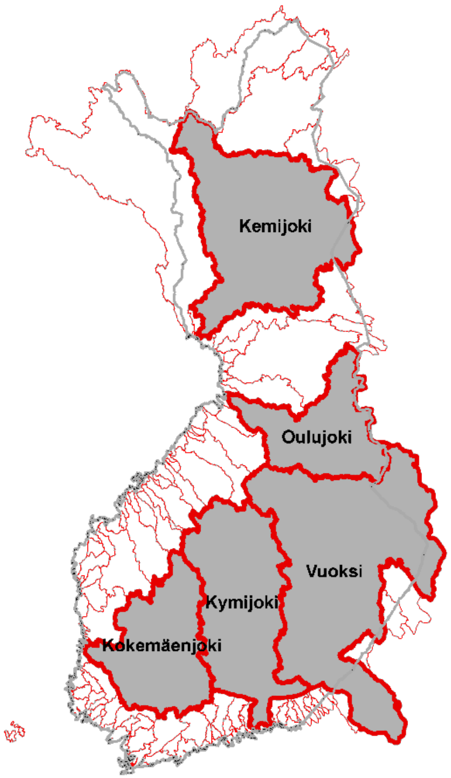
Hydropower, hydrology group

Used the CES climate scenarios to investigate effects of runoff changes on the production of hydropower, the most important renewable energy source for electricity in the Nordic area

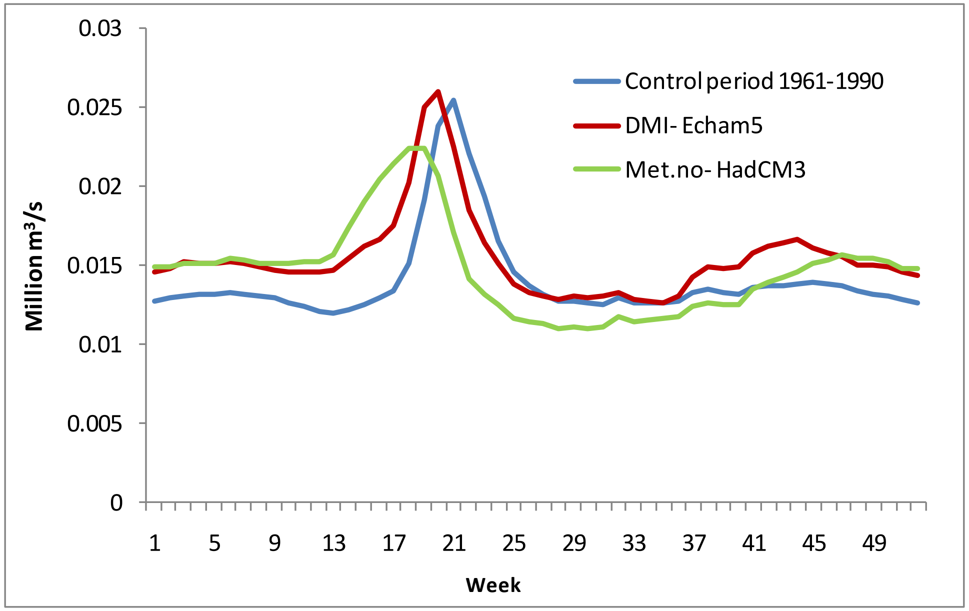
PI: Sten Bergström, Sveriges Meteorologiska och Hydrologiska Institut (SMHI)

- **Climate change effects on hydropower production**
- **Dam safety studies**
- **Improving interfaces between climate models and hydrological models**
- **Improving methodology to cope with impacts on lake and river regulation in a changing climate**
- **Compared Nordic design flood standards under present and future climate conditions**

Predicted runoff changes: Example from Finland

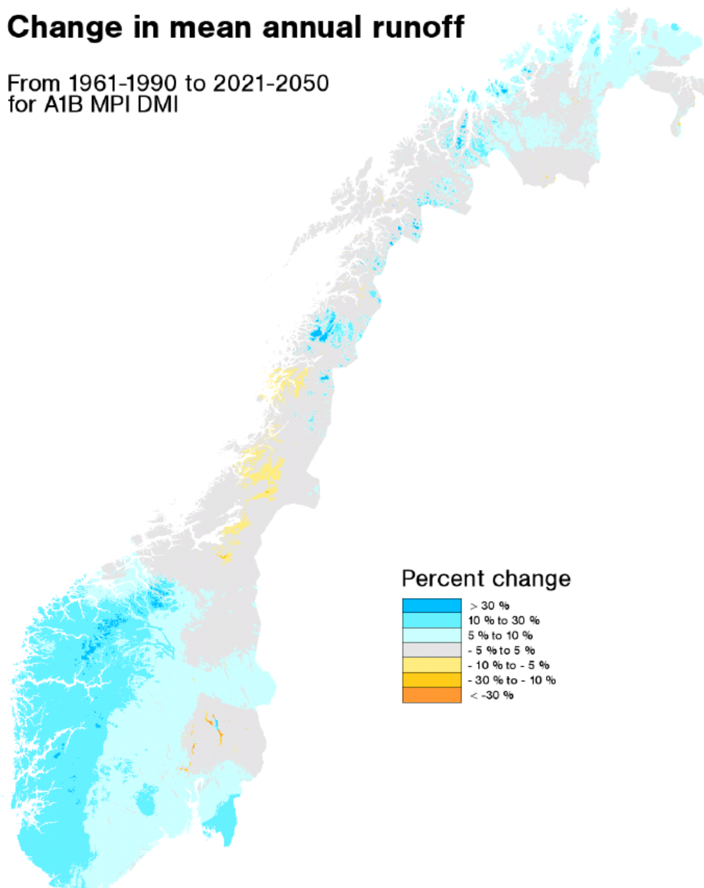


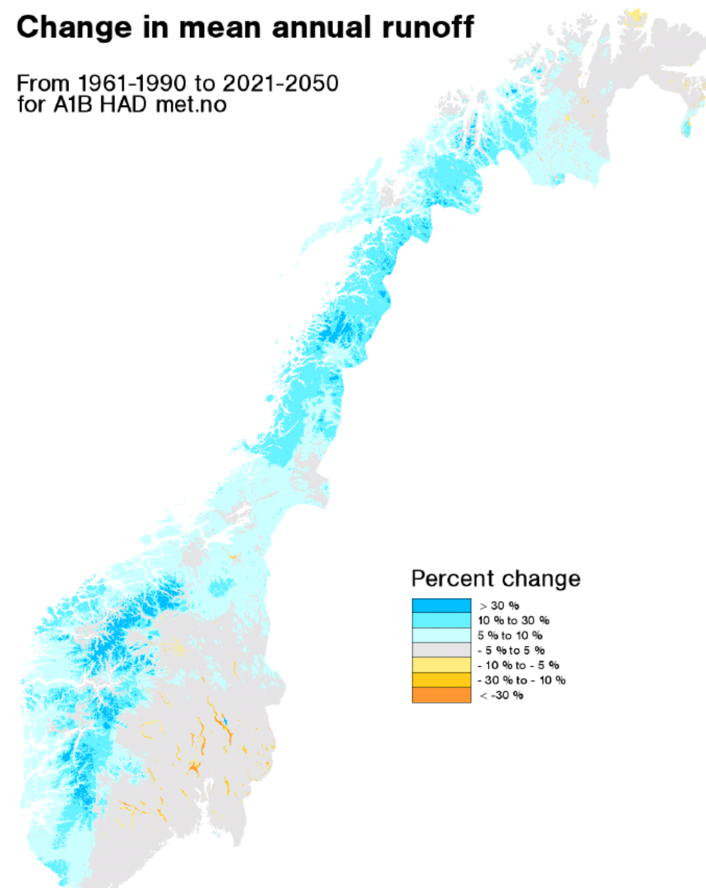
Location of five most important rivers in Finland harnessed for hydropower production



Discharge (weekly average) in the control period 1961-1990 and in 2021-2050 based on two scenarios. The scenarios indicate a 5-10% increase in annual runoff and a clear increase in winter runoff.

Predicted runoff changes: Example from Norway





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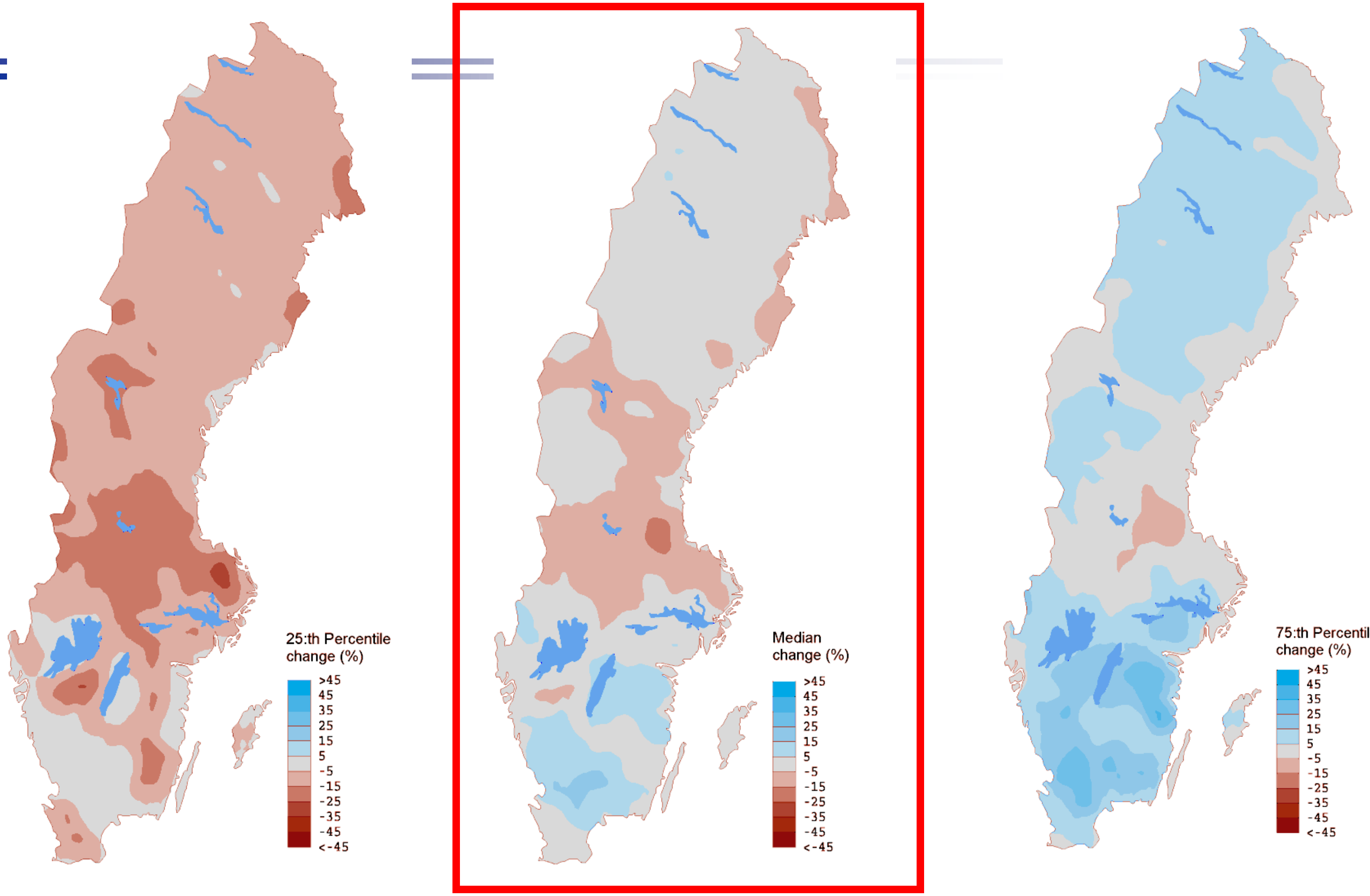
100-year floods in Sweden



Change in 100-year floods (%) in Sweden from the period 1963-1992 to the period 2021-2050. (Left and right diagrams indicate span of possible outcomes from 16 models).

Some conclusions from the hydrology group

- Little doubt that Nordic and Baltic hydropower systems will be affected strongly by a changing climate
- Seasonality of inflow into reservoirs changes – milder and wetter winters
- Large snowmelt floods likely fewer, but larger rain floods may occur
- Potential for hydropower production will generally increase
- Considerable uncertainty, regional scenarios vary greatly

The Wind Energy Group

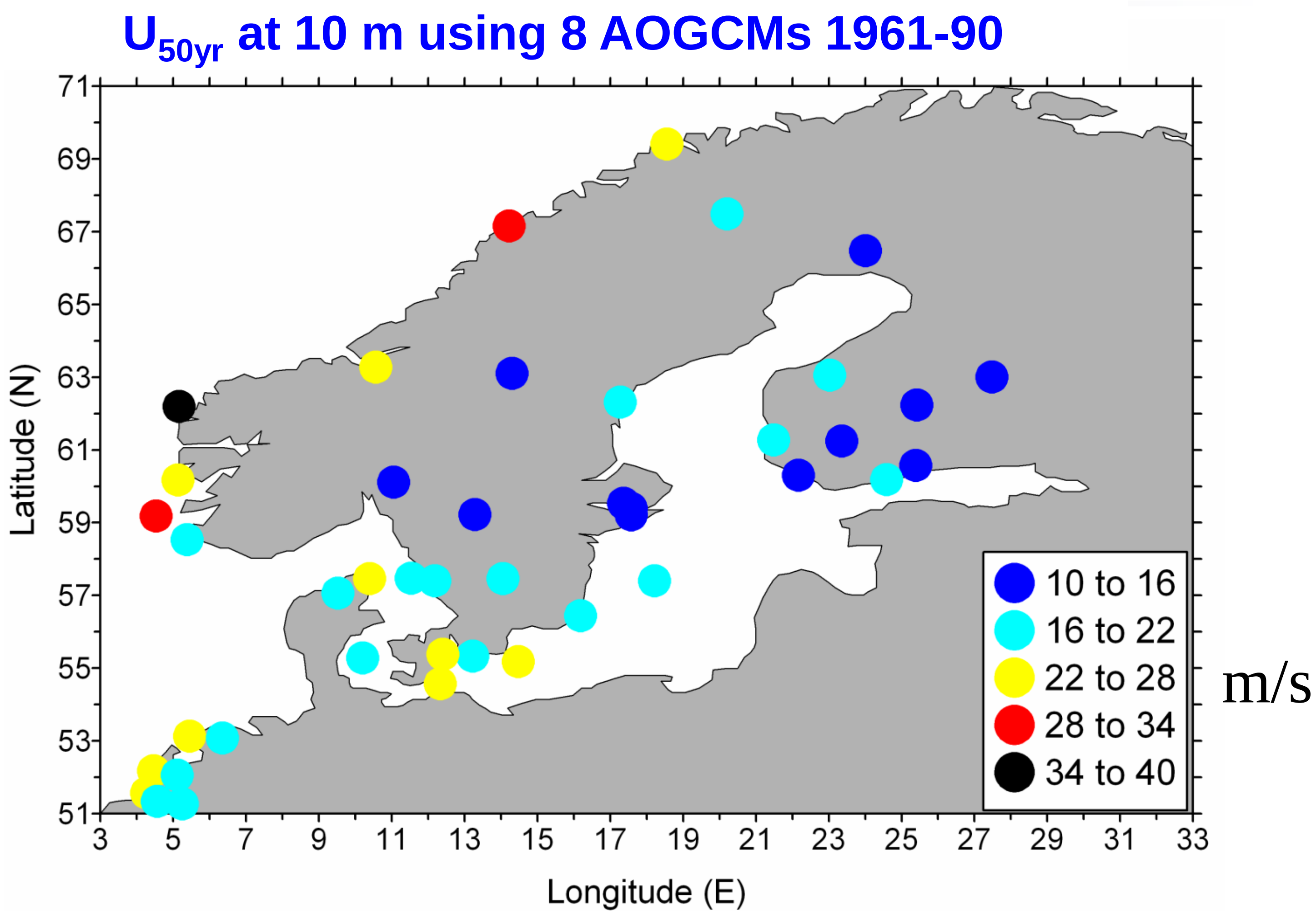
Modelled future wind climates, analysed climate change impacts on extreme wind and contributed to forecasts of the development of the Nordic electricity system in the coming 20-30 years.

PI: Niels-Erik Clausen, Risø Nationallaboratoriet, Danmarks Tekniske Universitet

- **Develop and evaluate tools for forecasting changes in wind climates**
- **Extreme wind atlas of the Nordic countries (50-year wind in 100 m height)**
- **Investigate climate change impact on extreme wind**

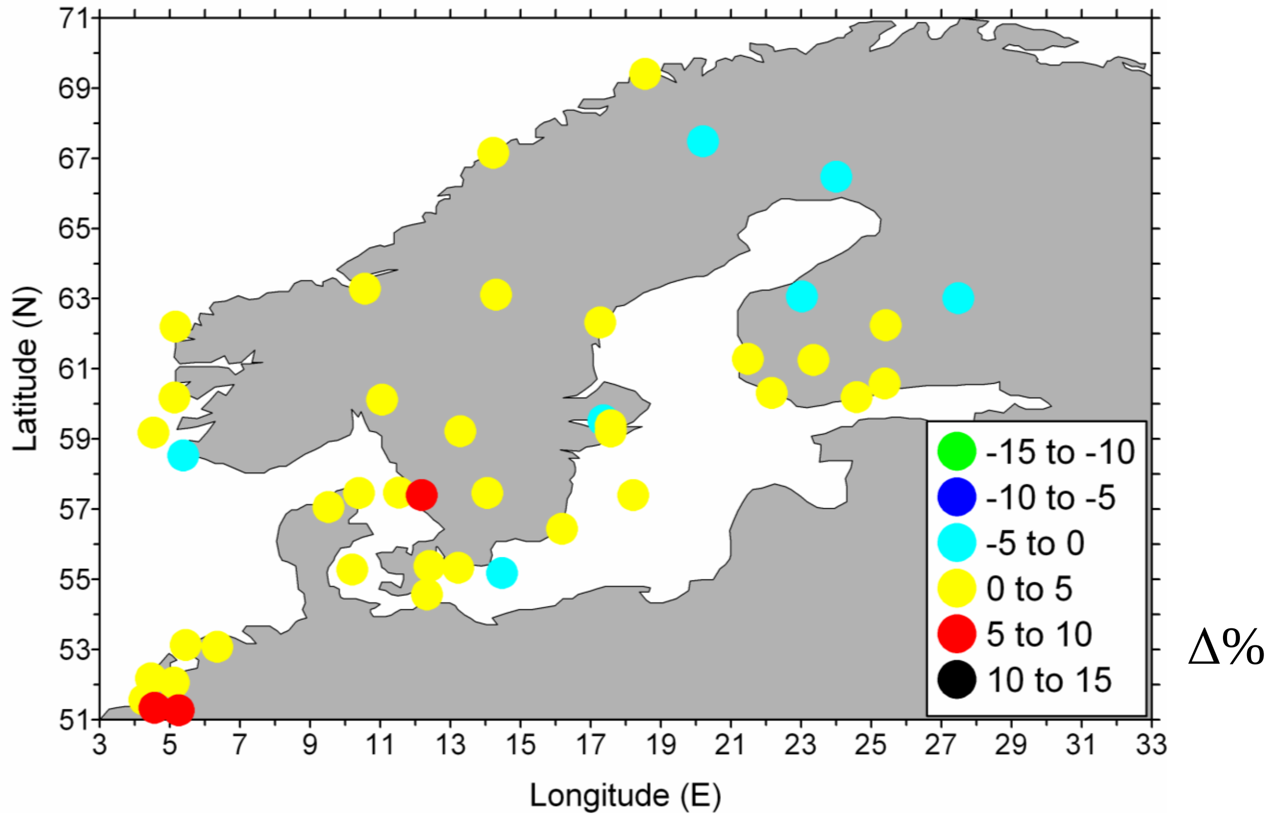
Empirical downscaling of eight models, control period

-



Change compared to 1961-90

The ensemble average change (%) in U_{50yr} using 8 AOGCMs



% change; 43 stations	2046-65	2081-2100*
<1%	26 stations	14 stations
>1%	17 (1-5%)	27 (1-10%)

* 2 show decrease

Results from the wind group

- In Northern Europe there are indications that we will see 0-10% increase of U_{50yr} in 2100 (63% of stations)
- 33% of stations show < 1% change
- 4% show decrease
- Extreme wind is sensitive to choice of model
- Extreme wind appears less sensitive to emission scenario
- Essential to use multiple models (AOGCMs) for analysis of climate impact of extreme wind

The Biofuels Group

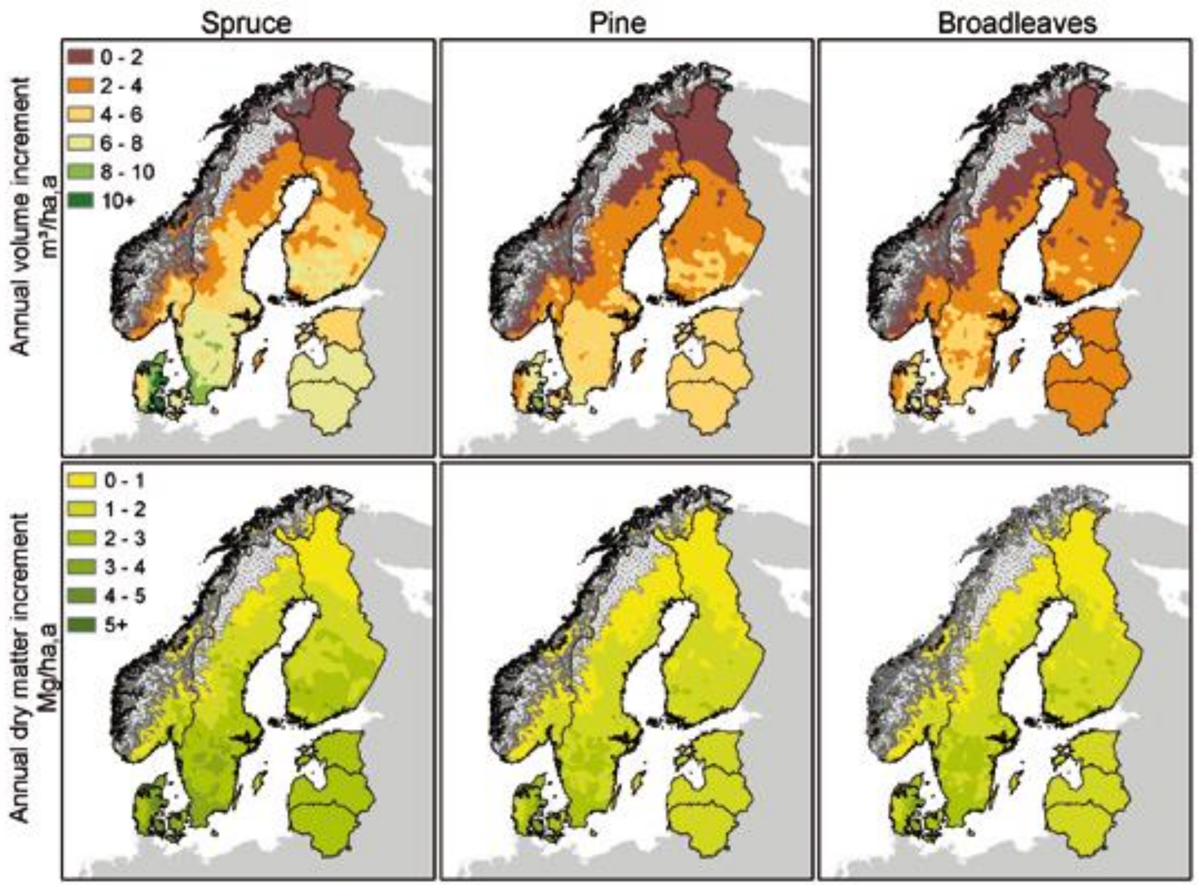
Utilization of various sources of bioenergy will increase in the Nordic countries in the future. What is the biomass production potential of forests at present and in the future, under likely climate scenarios?

PI: Seppo Kellomäki, University of Joensuu, Finland

- **Understanding the natural variability and predictability of bioenergy production**
- **Assessment of potential production of forest biomass for energy**
- **Assessment and development of forest management regimes and bioenergy production to substitute fossil fuels**

Results indicate that bioenergy production potential will have increased by the mid-21st century.

Increased forest growth in the Nordic-Baltic region



Annual mean stem volume growth (upper graphs) and annual
mass growth of stem wood (lower graphs).

The Risk Analysis Group

Uncertainty translates into riskier decisions within the energy sector – methods and tools for climate change risk assessment and adaptation strategies must be realised.

PI: Jari Schabel, VTT Technical Research Centre of Finland

- **An evaluation of risk under increased uncertainty to improve decision making in a changing climate**
- **Develop a Risk Assessment Framework (RAF) for use in climate change management within the energy sector**
- **General decision support regarding climate issues for the energy sector**
- **Support development of adaptation strategies and Adaptation Plan**

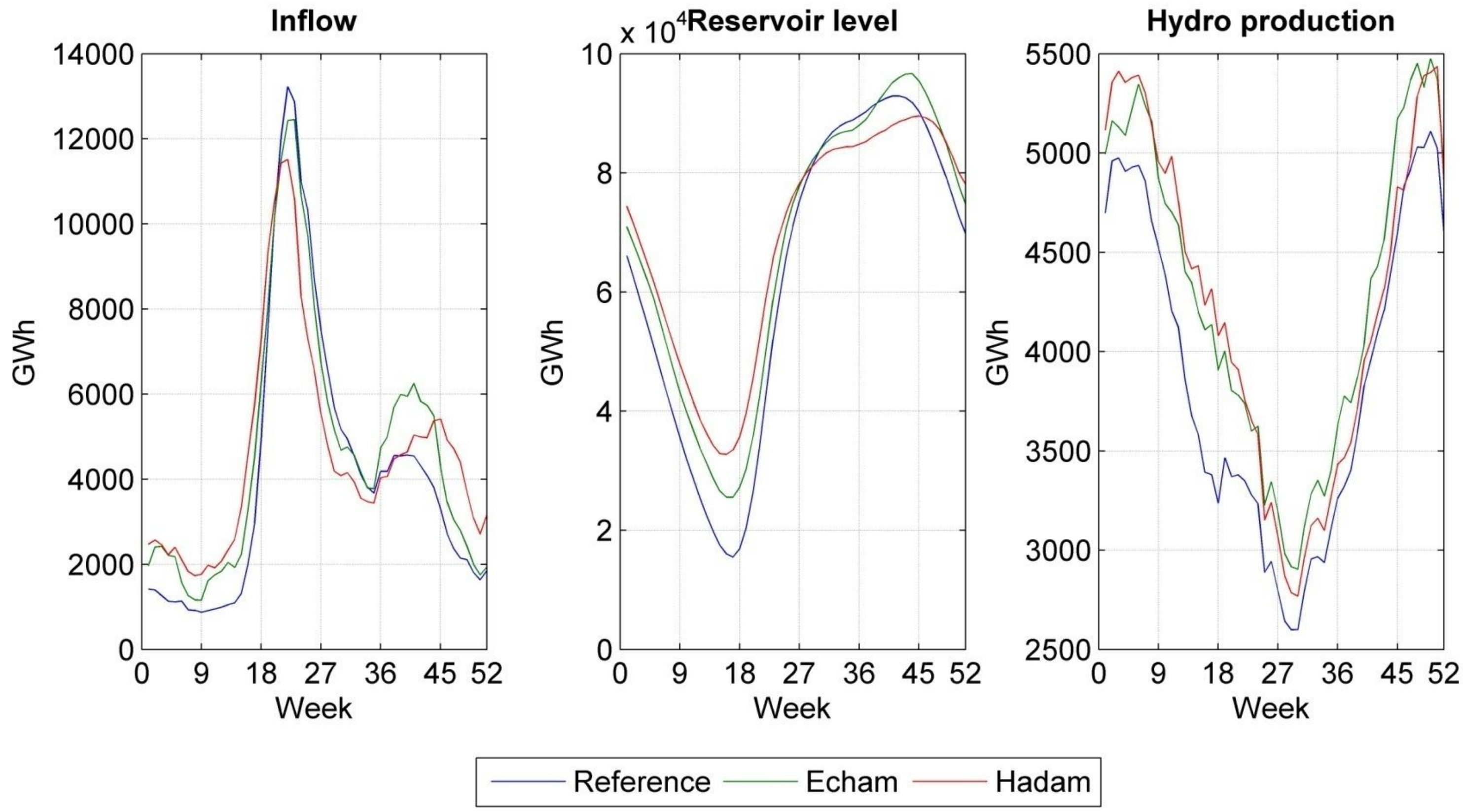
The Energy Systems Analysis Group

Used present climate data and future scenarios to simulate the operation of a given electricity system. Identified and quantified changes in generation of and demand for electricity resulting from changing climatic conditions.

PI: Birger Mo, SINTEF Energy Research, Norway

- **How do power generation, demand and transmission characteristics respond to expected changes in reservoir inflow and temperatures?**
- **SINTEF Energy Research´s EMPS model used to simulate the electricity system by 2020, taking into account forecasts of production and transmission capabilities, electricity demand, input fuel costs and CO_2 quota prices.**

Average annual hydropower characteristics for the NordPool area – reference period and 2 scenarios



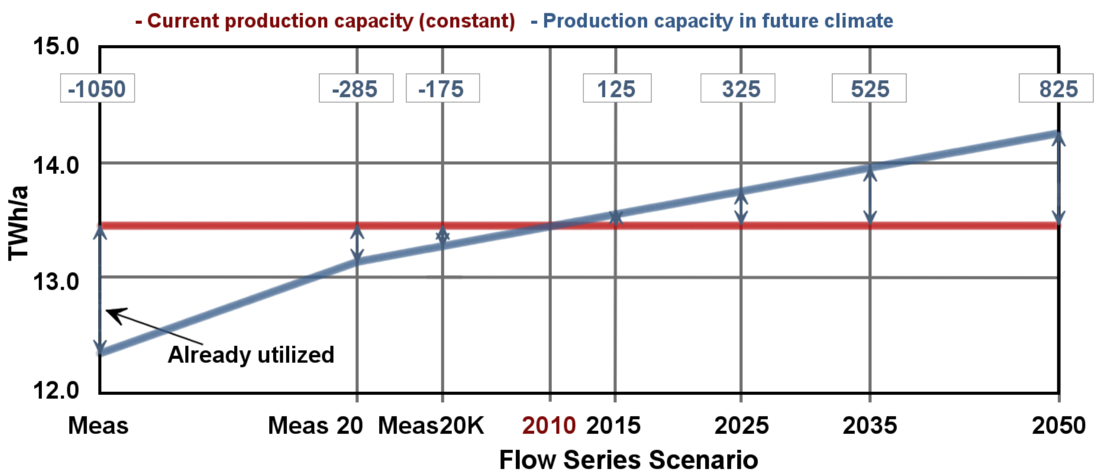
- **Greater inflow predicted, particularly in winter**
- **Less variation in reservoir levels over the year**
- **Increased hydropower potential predicted**

Some key results for 2020 (energy systems analysis)

- Average annual inflow will have increased by 12-13 %
- More inflow during winter, less or unchanged during summer
- Higher temperatures causes demand to decrease by 2-3%
- Thermal production is substituted by hydro production
- Less imports from and more export to continental Europe

Hydropower in Iceland – impacts of a warmer climate

- Runoff increase of 27-84% for harnessed rivers expected until 2050.
- This translates into 20% increase in potential energy in river flows to existing power stations.
- Current systems can only utilize this to increase power production by 8.5%, because of limited additional reservoir capacity.
- Results being used in analyses of redesign and upgrades of current power stations.



Possible production increase in warming climate.
Numbers in boxes show difference between current (2010), future and past production capacity **(in GWh/a)**

Adaptation in the energy sector

- Redesign of hydropower plants (many due for restoration) including
  - dam safety in light of different risks
  - environmental flows
  - different seasonality
  - more firm power
  - changes in extreme flows
  - changes in river courses for glacial rivers
  - Changes in extraordinary floods, glacial outburst floods (jökulhlaup)
- Operations and planning of hydropower is now based on scenarios rather that past statistics. Has generated tremendous benefits in Iceland

Top Research Initiative:

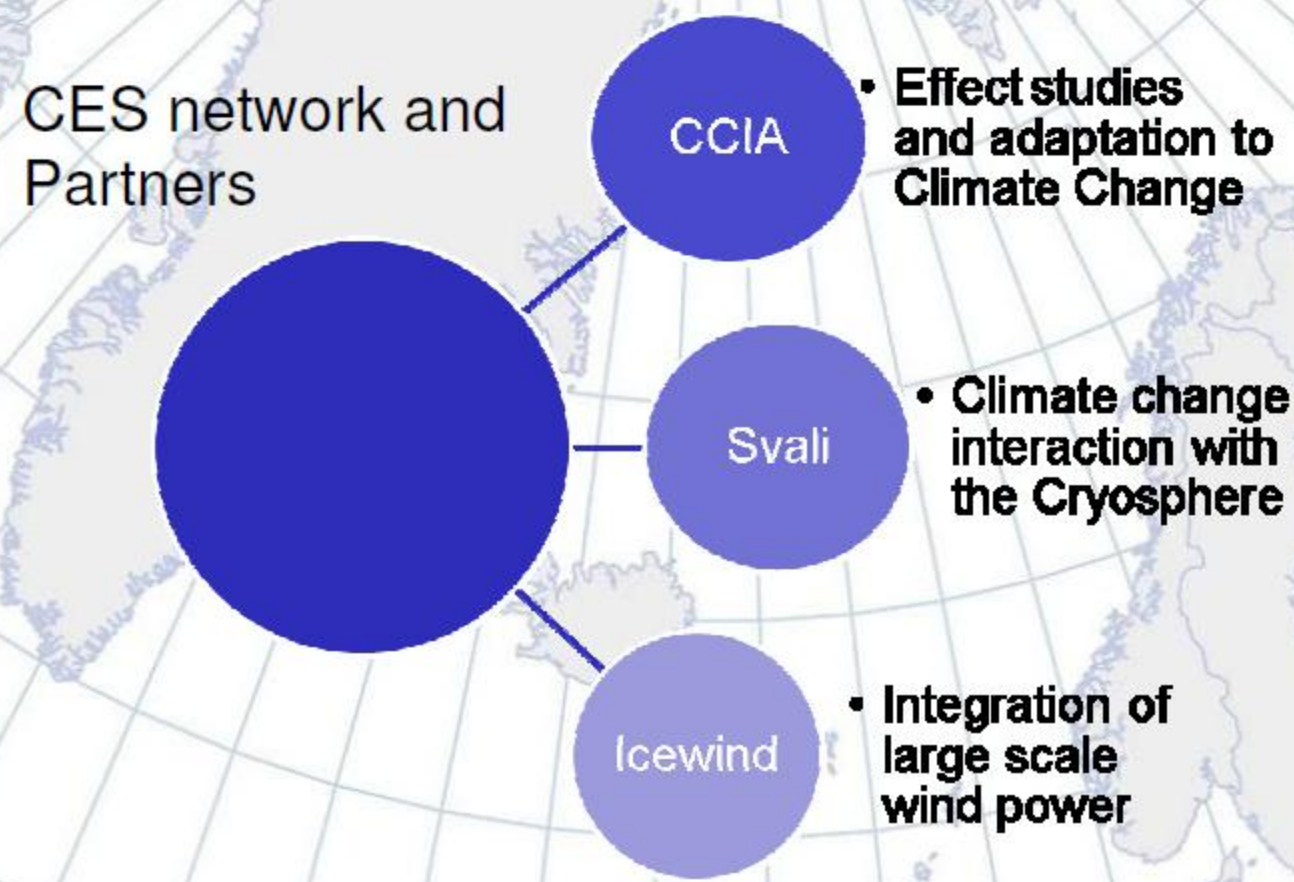
Toppforskningsinitiativet (TFI)

Budget: DKK 400 million over 5 years

Joint funding through:
- Nordic Council of Ministers
- National Funding Bodies
- NordForsk
- Nordic Innovation Centre
- Nordic Energy Research

Programme timeframe: 2009-2013

CES approach to TFI



Icewind project

Icelandic Met Office

DTU

IceWind project – key figures

- Title: **Improved forecast of wind, waves and icing**
- Project period 1. September 2010 – 31. August 2014
- Overall budget 20.8 mill NOK
- Financial support TFI 12.3 mill NOK
- Ekstern finansiering 8.5 mill NOK
- Partners: 13
- 375 man-months (45,000 hours) over 4 år
- Coordinator Risø DTU (NECL)
- 4 PhD projects planned: Two in Iceland, one in Denmark and one in Sweden

IceWind work packages

- WP 1 Icing (lead VTT)
  - Atlas of icing for Iceland and Sweden, forecast of icing, est. of losses due to icing
- WP 2 Iceland (lead Iceland met office - IMO)
  - Wind atlas, identification of sites, technical and market integration studies
- WP 3 Forecast and O&M (lead met.no)
  - Offshore meso-scale effects of large wind farms incl. wakes, short term forecasting, maintenance strategies and availability issues
- WP 4 Power and energy aspects (lead Risø)
  - Spatial and tempral variability of wind resource, forecast errors and their impact on the Nordic power grid and balance market.

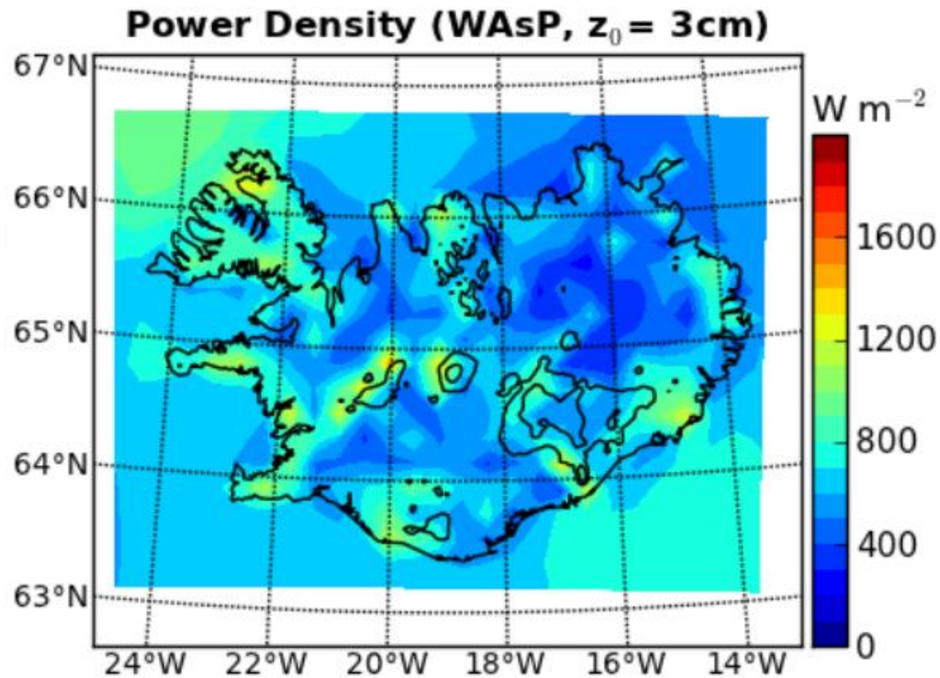
Wind energy in Iceland

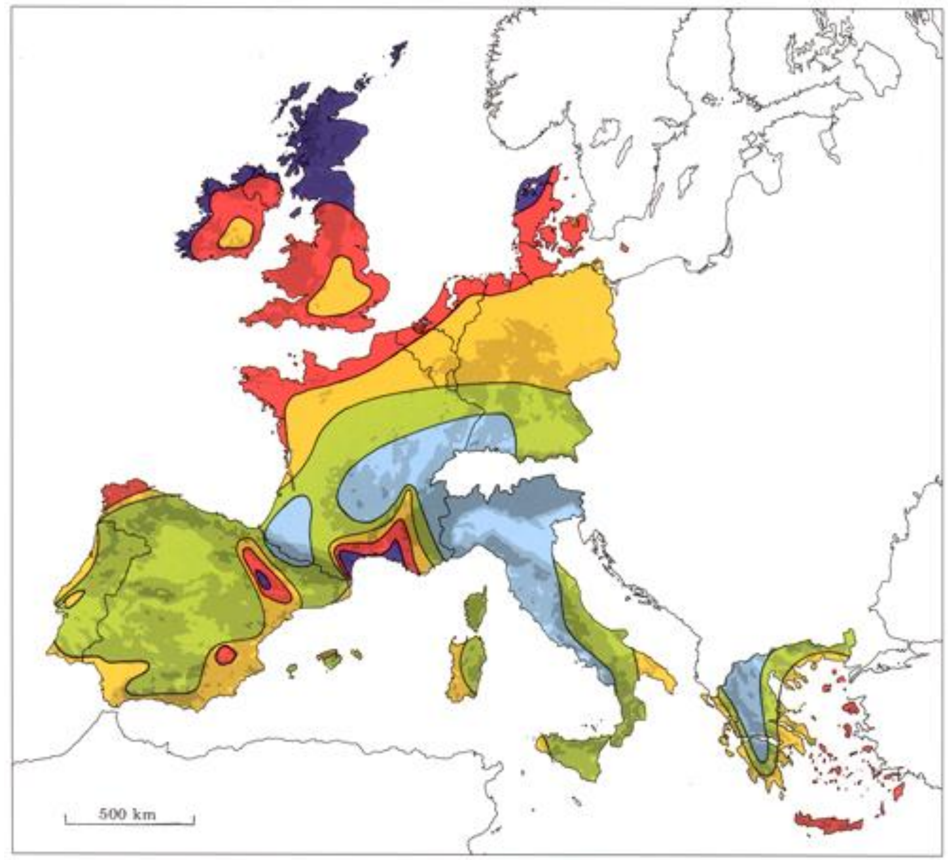
Icelandic Met Office

- The Icewind project is the first big wind energy project in Iceland
- Nordic project, but in Iceland the focus is on
  - Icing atlas
  - Wind Atlas, on shore and off shore
  - Intergration of wind energy in the Icelandic energy system
    - Physical system connectivity and stability
    - Market issues

Based on WRF winds
50 mAGL; all sectors

Veðurstofa Íslands

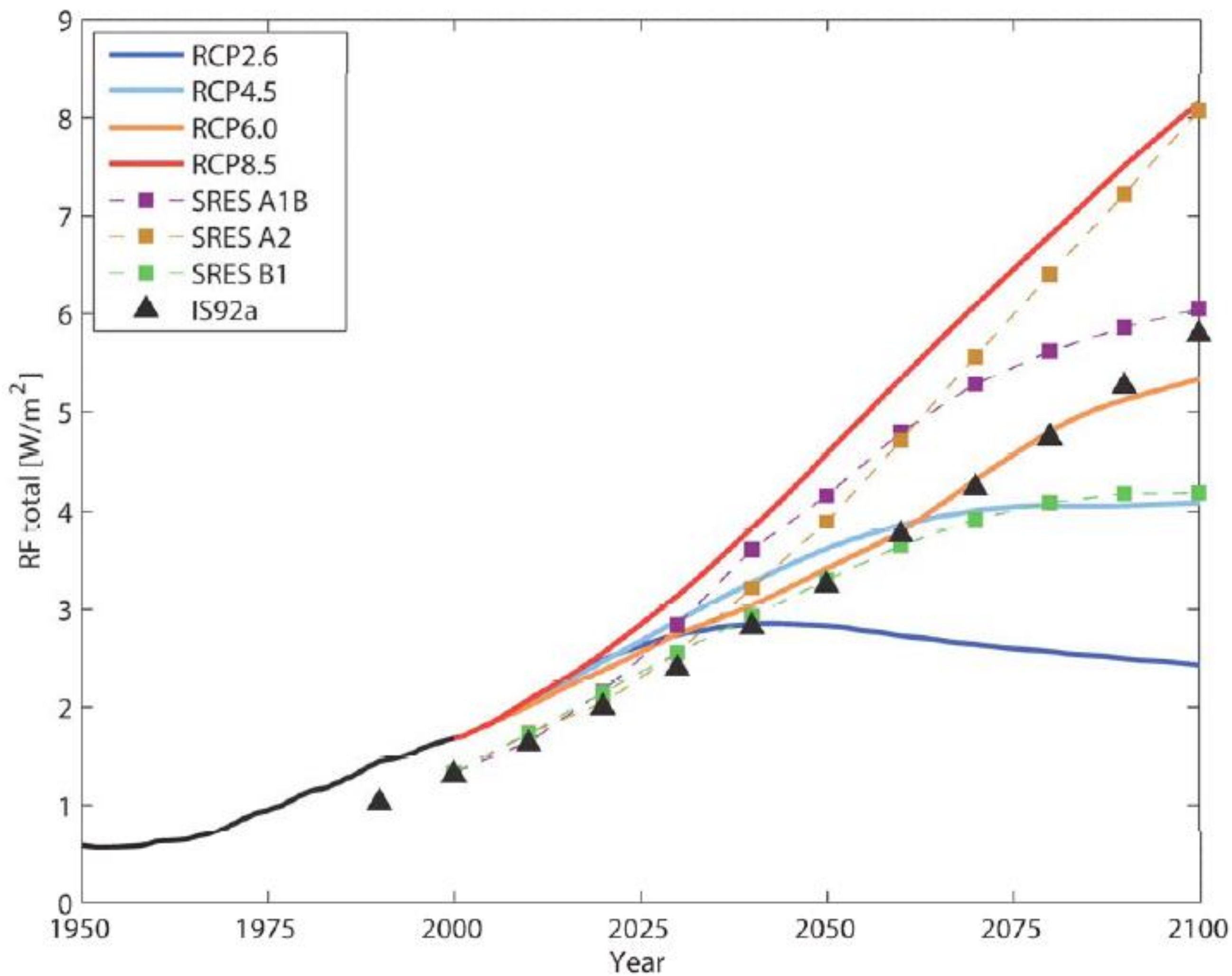




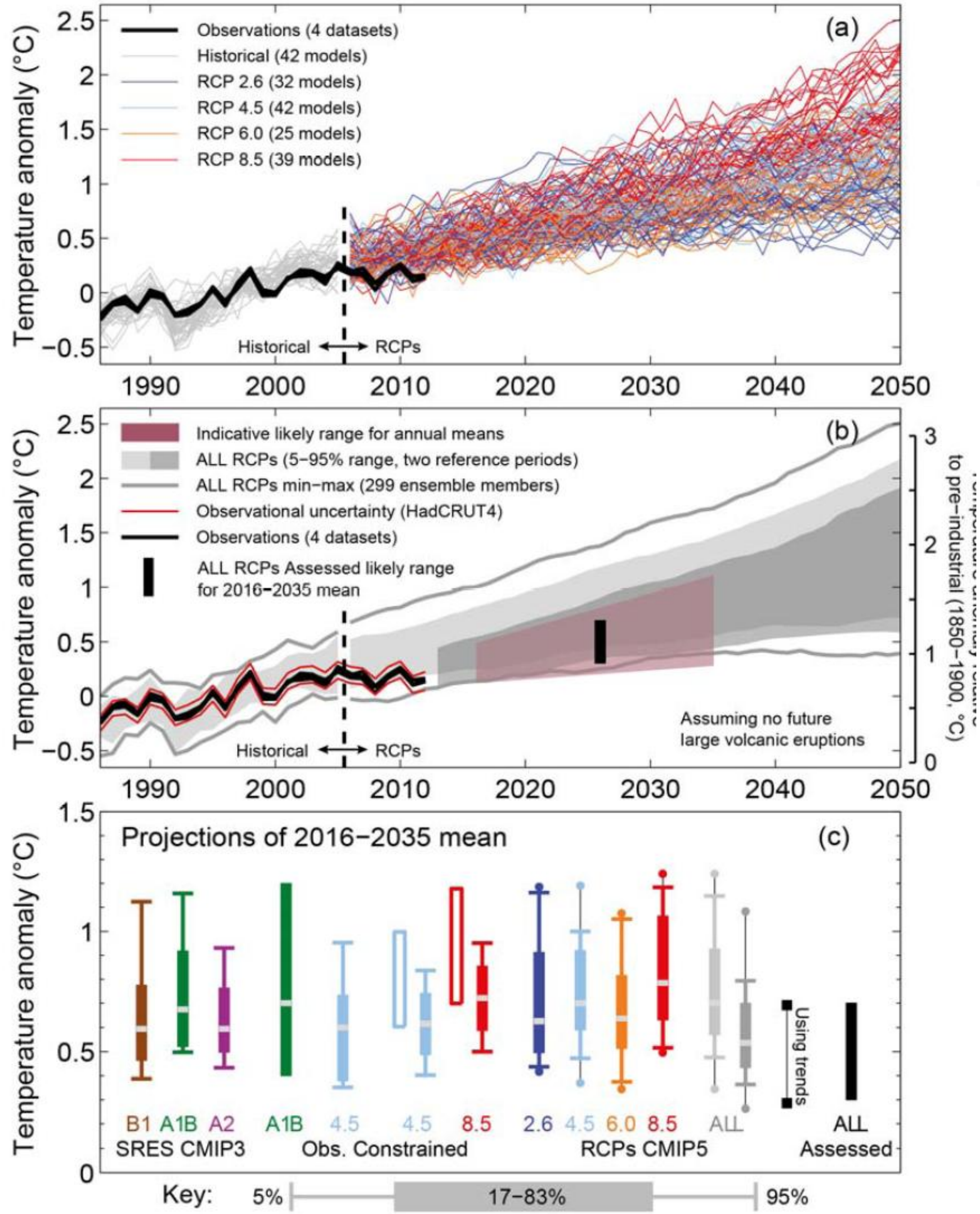
Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Values ~400-1200 Wm^2
Comparable or higher than highest
Values in European Wind Atlas (1989)

Emission scenarios

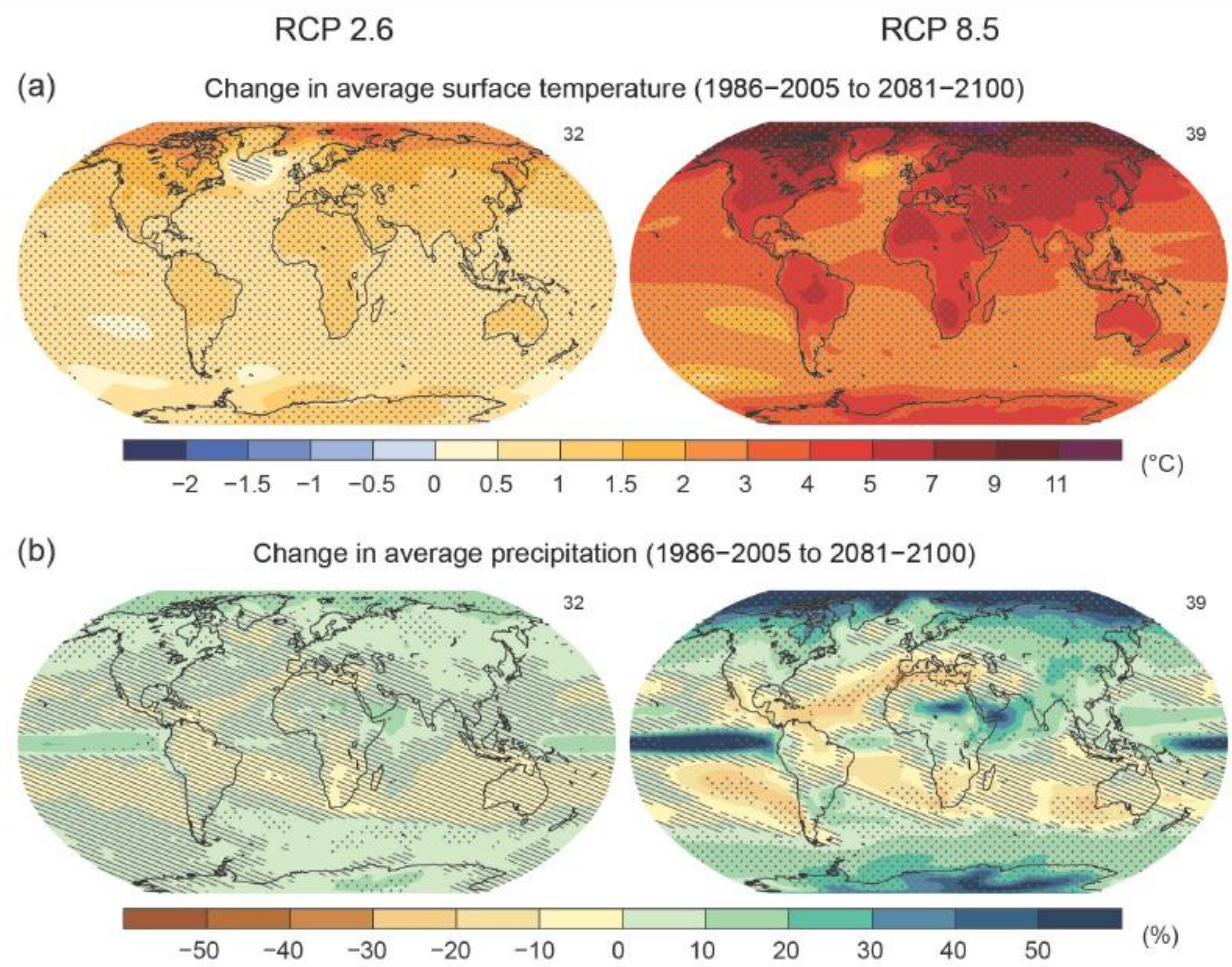


Global mean temperature near-term projections relative to 1986−2005



Longer term scenario calculations

- Changes in lowest scenario (RCP2.6) and highest (RCP8.5) between the period 1986-2005 and



Sea level rise

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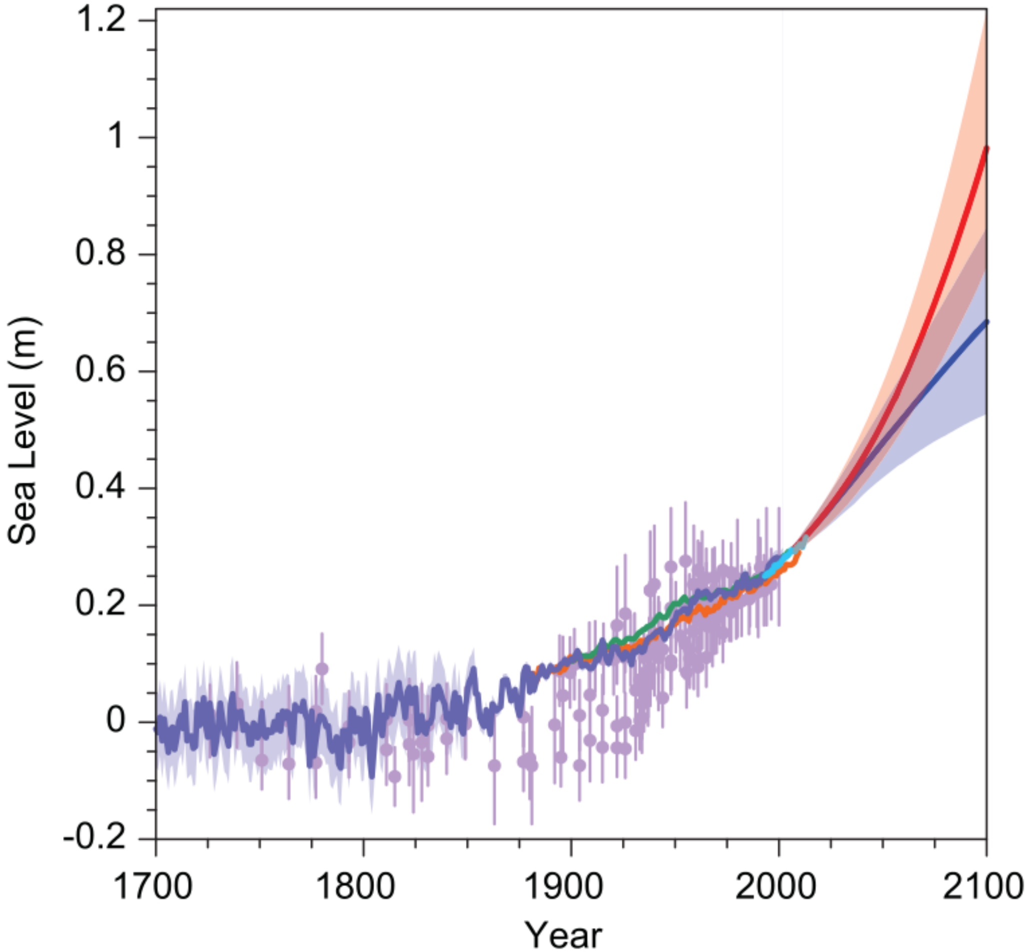
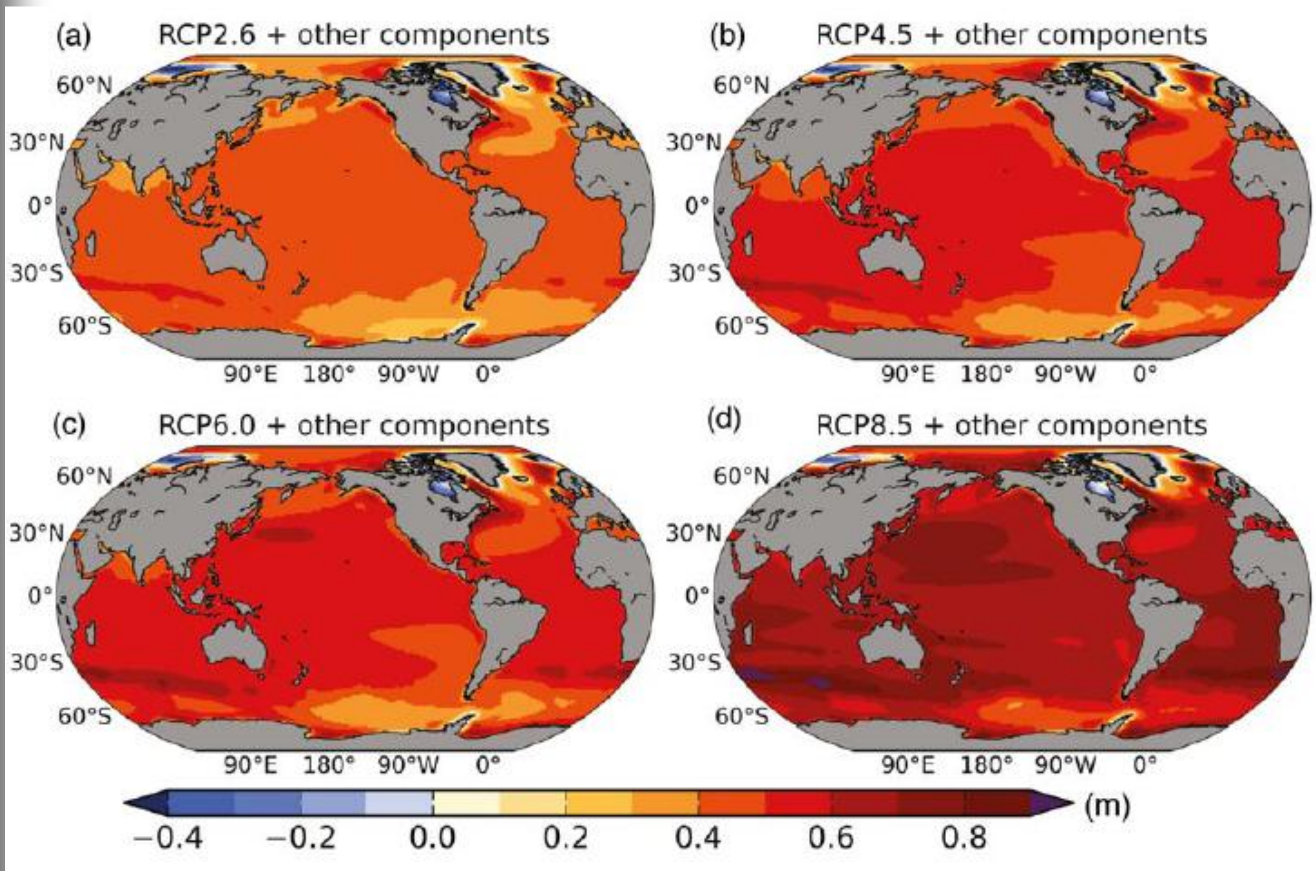
- Based on different climate scenarios the global sea level will rise from ~0.6 to ~1 m by 2100 depending on scenarios
  - Uncertainty for each scenario is considerable
- Regional variations will be large



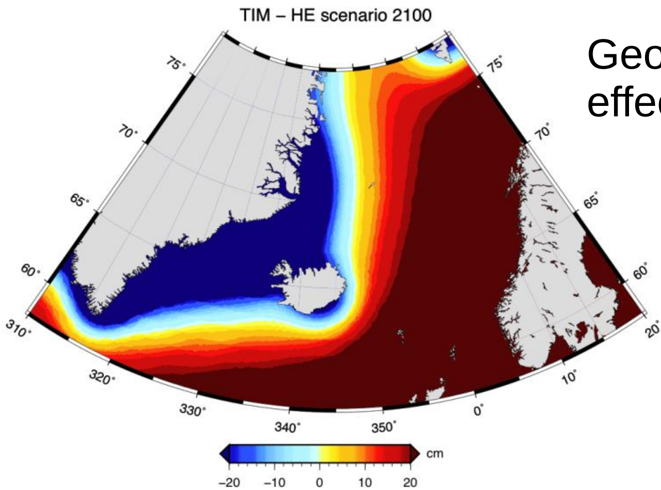
IPCC, AR5

Regional sea level scenarios for 2081-2100 relative to 1986-2005

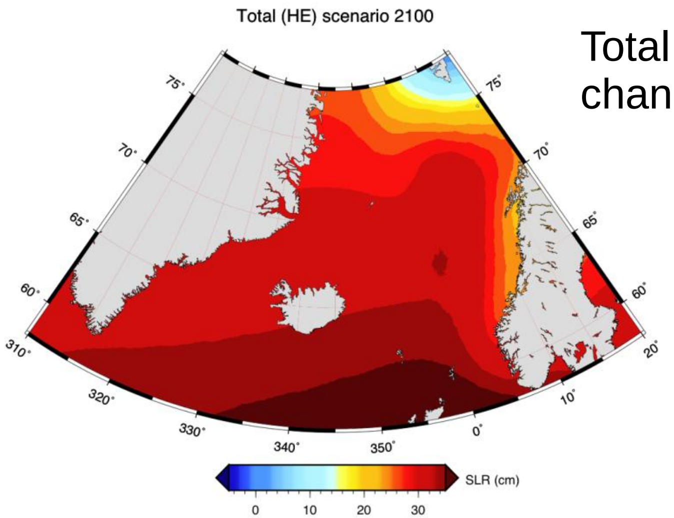


Sea level rise near Iceland

- A surprising regional factor is that sea level near large glaciers and ice-sheets may drop due to geoid changes as a result of icemelt.
- In an *Ice2Sea* scenario with 61 cm global sea level rise the change rise around Iceland is only 25 – 30 cm.
- Does not take local effects such as subsidence or uplift into account



Geoid effect



Total change

(Georgio Spada, Ice2Sea)

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