Climate Variability and Change Impacts on Hydropower Infrastructure in Norway and Alaska

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Outline

• Physical Infrastructure
• Climate sensitivity
• Impacts of climate change
• Impacts of climate variability
• Market setting
**Bradley Lake**
Two unit 45 MW plant
SE Grid – Existing and Proposed

FIGURE 1-2
Southeast Alaska
Existing and Proposed
Transmission Lines
Southeast Alaska Intertie Study
Scandinavian Electric Grid

Global Energy Network Institute
Climate Sensitivity of Hydropower Systems
Energy Requirement – 2.1%

SITKA Facilities, courtesy Chris Brewton
Energy production trends in Norway and Sweden

Energy supply in Norway and Sweden comes from only two sources, both of which are climate dependent (directly or indirectly).

They share a physical power grid and an energy derivatives market.

They are each other’s biggest trade partners for physical power.

Trend, not related to NAO, Trade off
Projected temperatures and infrastructure lifespan

IPCC, 2007
Long-term Climate Change Projections: good for hydropower
IPCC projected water cycle changes (missing permafroost, glacier feedbacks)

Meehl et al., 2007
Projected spatial snow cover change

IPCC AR4, 2007
Climate Variability:
working on multiple scales
Impact of ENSO at SEAK Stations
Impact of ENSO at SEAK Stations

PCP Climatology shift w/ENSO

- Juneau EL NINO
- Juneau LA NINA
- Juneau Climatology
- Ketch EL NINO
- Ketch LA NINA
- Ketch Climatology
- Sitka EL NINO
- Sitka LA NINA
- Sitka Climatology

mm

month

0  2  4  6  8  10  12
Impact of ENSO at SEAK Stations
ElNino/AO- minus LaNina/AO-

ElNino/AO+ minus LaNina/AO+

Difference Plots: precipitation

Bond and Harrison, 2006
Physical Impacts of the NAO

data

NAO Index (Jones 1997) and:
correlation with DJFM SST (Kaplan et al 1998)
correlation with DJFM SAT (NCDC/GHCN)
covariance with DJFM SLP at 0.3 HPa contour intervals (NCEP reanalysis)

Trends:
upward?
persistent?

NAO Index is the highly correlated with climate fields
Story Preview: Impacts of the NAO on Scandinavia’s Climate and Energy Sector

First mode of variability in precip and temp look like the NAO in time and space

EOFs

PCs

Reservoir levels show similar patterns of variability (stations, not PC)

Data: Xie & Arkin, NCEP, Statistics Norway

= Bergen, will use this from now on

= Major reservoirs

Red=DJFM
Market Setting
A conceptual model, illustrated by the 1996-1997 NAOI negative event, provides a hypothesis for the physical mechanisms behind an NAO impact on the energy sector.

S = amt producers willing to sell for each price on the market, D = same, but for consumers buying.
Norskhydro streamflow 
\[ r = +0.7 \]

Reservoir level 
\[ r = +0.6 \]

Hydropower production anomaly 
\[ r \approx +0.5 \]

Precipitation anomaly (1994-5 off) 
\[ r = +0.8 \]
Hydropower consumption anomaly
\[ r \sim -0.5 \]

Temperature anomaly
\[ r = 0.7 \]

1994-1995 off
Deregulation and privatization in the 1990s allowed the establishment of the first international market for energy derivatives, called Nordpool.
Correlation tests seem to support the proposed mechanism. Can the NAO Index then be used to predict spot prices?

In this realization, I assumed regression coefficients are known, but not NAOI.

Prices predicted solving $Ax=b$ by regression.

Floods in Sweden
Figure 9: Norwegian energy spot prices are predicting using NAOI covariance method described in text. The NAOI is plotted as yellow bars. The black curves in both 9a and 9b are the actual spot prices. For the red curve in 9a, only the past covariance is used to estimate the price. The red dashed curve in 9b was trained over entire period.
Figure 10a-f: Financial figures regarding the hydropower sector in Norway plotted against the NAO Index.
Big climate differences:

Most climate variability in Norway is explained by the NAO; climate variability in SEAK is more complex (a combo of multiple modes of variability)

ENSO driven variability in SEAK is predictable on a time scale that is meaningful for management, while NAO is not
Big economic differences:

Vastly different markets; Norway is a quasi state-run, internationally connected grid, SEAK is largely isolated run by very small municipalities and no obvious external market.

Most of SEAK’s tiny communities are saddled with high levels of debt service. Not the case in Norway, absorbed by the Federal economy.

Norway’s hydropower risk is commoditized, SEAK’s is not. Maybe the ratepayers lose, regardless.
Questions?

Contact: jcherry@iarc.uaf.edu
Talking Points

- Climate drivers in Alaska and the Arctic and how they impact hydropower
- Long-term climate change versus climate variability on interannual, decadal, and longer timescales
- Predictive tools: useful for management
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  – Large scale global ocean atmosphere circulation
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• Climate drivers in Alaska and the Arctic and how they impact hydropower
  – Large scale global ocean atmosphere circulation
  – Regional ‘quick’ feedbacks from ice edge, snow cover, Aleutian Low/Siberian High or Icelandic Low/Azores High
  – Regional ‘slow’ feedbacks from glaciers and permafrost (though catastrophic change can occur quickly)
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Climate Change
Observed Temperature Change in Alaska

Total Change in Mean Annual Temperature (°F), 1949 - 2008

Statewide Average: 3.1°F

Alaska Climate Research Center
Geophysical Institute, University of Alaska Fairbanks
# Observed Temperature Change by Season

## Total Change in Mean Seasonal and Annual Temperature (°F), 1949 - 2008

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<th>Region</th>
<th>Location</th>
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Alaska Climate Research Center
Geophysical Institute, University of Alaska Fairbanks
Projected temperature, precipitation, and pressure changes

*IPCC AR4, 2007*
Climate Variability
Observed Historical Average Temperature Anomalies by Season for SEAK
Observed Historical Precipitation Anomalies by Season for SEAK
Observed Climate Variability: PDO

IPCC AR4, 2007
Observed Climate Variability: ENSO

IPCC AR4, 2007
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  - Probabilistic seasonal forecasts
  - Longterm climate projections
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NWS RFC Alaska-Pacific
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Predictability of ENSO

Figure 6. Forecasts of sea surface temperature (SST) anomalies for the Niño 3.4 region (5°N-5°S, 120°W-170°W). Figure courtesy of the International Research Institute (IRI) for Climate and Society. Figure updated 19 January 2010.
Talking Points

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Climate Change

100-year and longer downscaled projections of temperature and precipitation for AK under various scenarios of Greenhouse Gas emissions

Projections of likely changes in soil temperatures, permafrost distributions and impact on groundwater storage
Temp Projections from SNAP for Southeast, AK

3.5-5.2 °C/130 yrs

Southeast Alaska: Mean Annual Temperature

Graph showing temperature projections with lines for CGCM3.1 (A1B), ECHAM5 (A1B), GFDL2.1 (A1B), HADLEY (A1B), and MIROC (A1B) models from 1980 to 2100.
Precip Projections from SNAP for Southeast, AK

23-35 mm/130 yrs

Southeast Alaska: Mean Annual Precipitation
Other things to consider…
Monitoring!!!!!

Very little in SEAK, despite importance of hydropower. Compare to Norway

Temperature, Precipitation, Snow depth, ET, discharge, Glacier mass balance & change over time

AEL&P has USDA/NRSC Snotel site. Monitoring need not be costly!
Sedimentation’s impact on Hydropower

Sedimentation can reduce the size of the reservoir and causes abrasion of turbines and other infrastructure.

Erosion and climate are strongly coupled.

Erosion may be accelerated by melting of glaciers in the watershed.
Bottom line

• Climate Change DOES matter, but our short observational records in Alaska make it difficult to separate climate change from natural multi-decadal variability. (Attribution problem). There are also data quality problems, especially for measurements of precipitation and discharge.

• Based on our short record and a small number of studies, about half of the observed climate change in Southeast may be attributable to long-term climate change and about half may be attributable to natural climate variability on decadal and multi-decadal timescales.
Bottom Line

• There is high inter-annual variability in climate conditions throughout SEAK. Less than 25% of this is explainable by ENSO or PDO conditions! Other dynamics, i.e. PNA, AO, and random variability are also factors.

• However, seasonal prediction is more accurate in SEAK than most parts of the U.S. This is the effect of PDO persistence, steady long-term warming, and variance explained by ENSO, which is typically predictable 6-9 months in advance.
Bottom Line: Recommendations

- Expanded/improved observational networks of temperature, precipitation/snow, runoff, and ET, especially at higher altitudes
- Combined with Climate Change Projections and
- Seasonal Prediction
- Will decrease risk in hydroelectric power management and planning for SEAK
Juneau Climate Anomalies

2009-10 Temperature Summary (Juneau)
Juneau Climate Anomalies

Cumulative Precipitation for 2009 - 2010 (Juneau)

- 2009 - 2010 Season
- Normal
Juneau Climate Anomalies
SE Grid – Existing and Proposed