Impacts of Climate Change and Variability on Hydropower Systems: results from Southeast Alaska and Scandinavia providing lessons for Susitna

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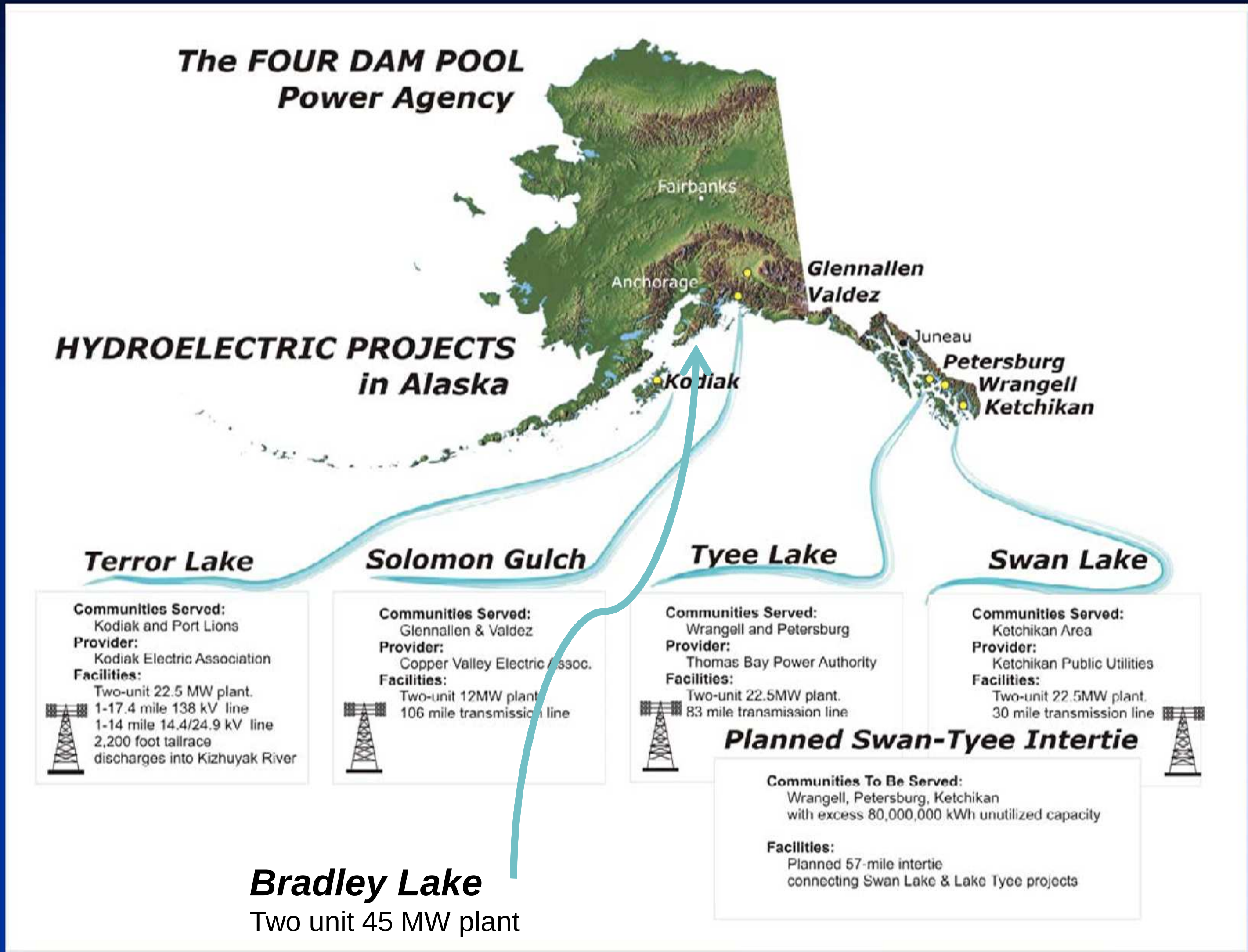
Outline

- Physical Infrastructure
- Climate sensitivity
- Impacts of climate change
- Impacts of climate variability
- Market setting
- Lessons for Susitna


The FOUR DAM POOL
Power Agency
HYDROELECTRIC PROJECTS
in Alaska
Fairbanks
Anchorage
Glennallen
Valdez
Juneau
Kodiak
Petersburg
Wrangell
Ketchikan
Terror Lake
Communities Served:
Kodiak and Port Lions
Provider:
Kodiak Electric Association
Facilities:
Two-unit 22.5 MW plant.
1-17.4 mile 138 kV line
1-14 mile 14.4/24.9 kV line
2,200 foot tailrace
discharges into Kizhuyak River
Solomon Gulch
Communities Served:
Glennallen & Valdez
Provider:
Copper Valley Electric Assoc.
Facilities:
Two-unit 12MW plant
106 mile transmission line
Tyee Lake
Communities Served:
Wrangell and Petersburg
Provider:
Thomas Bay Power Authority
Facilities:
Two-unit 22.5MW plant.
83 mile transmission line
Swan Lake
Communities Served:
Ketchikan Area
Provider:
Ketchikan Public Utilities
Facilities:
Two-unit 22.5MW plant.
30 mile transmission line
Planned Swan-Tyee Intertie
Communities To Be Served:
Wrangell, Petersburg, Ketchikan
with excess 80,000,000 kWh unutilized capacity
Facilities:
Planned 57-mile intertie
connecting Swan Lake & Lake Tyee projects
Bradley Lake
Two unit 45 MW plant

SE Grid – Existing and Proposed

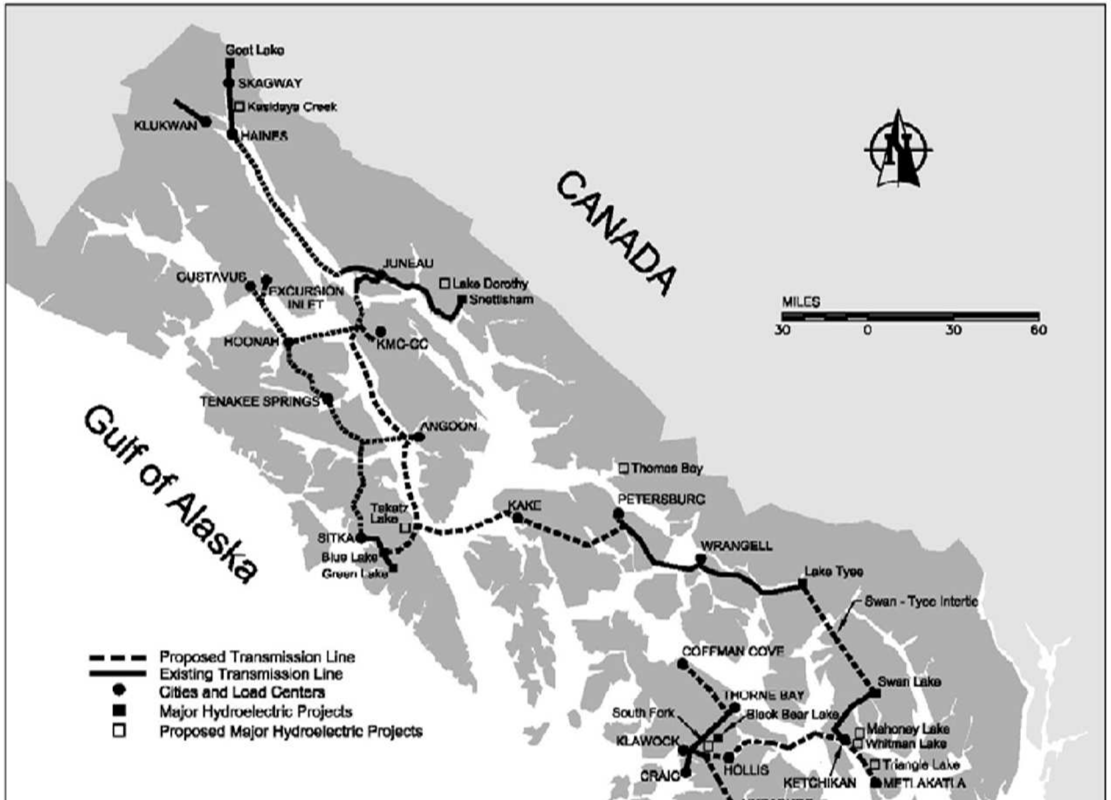
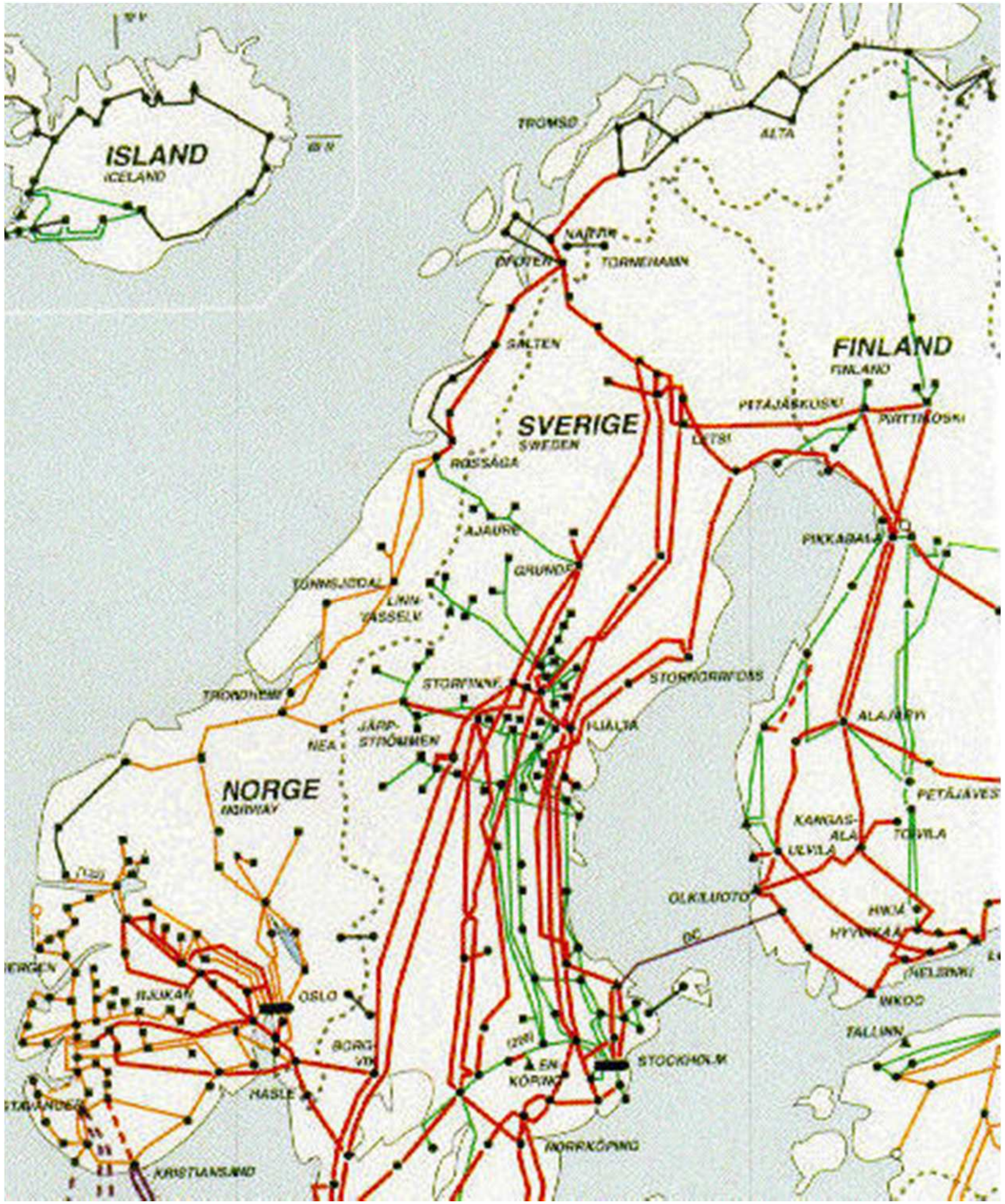


FIGURE 1-2
Southeast Alaska
Existing and Proposed
Transmission Lines
Southeast Alaska Intertie Study

The FOUR DAM POOL Power Agency

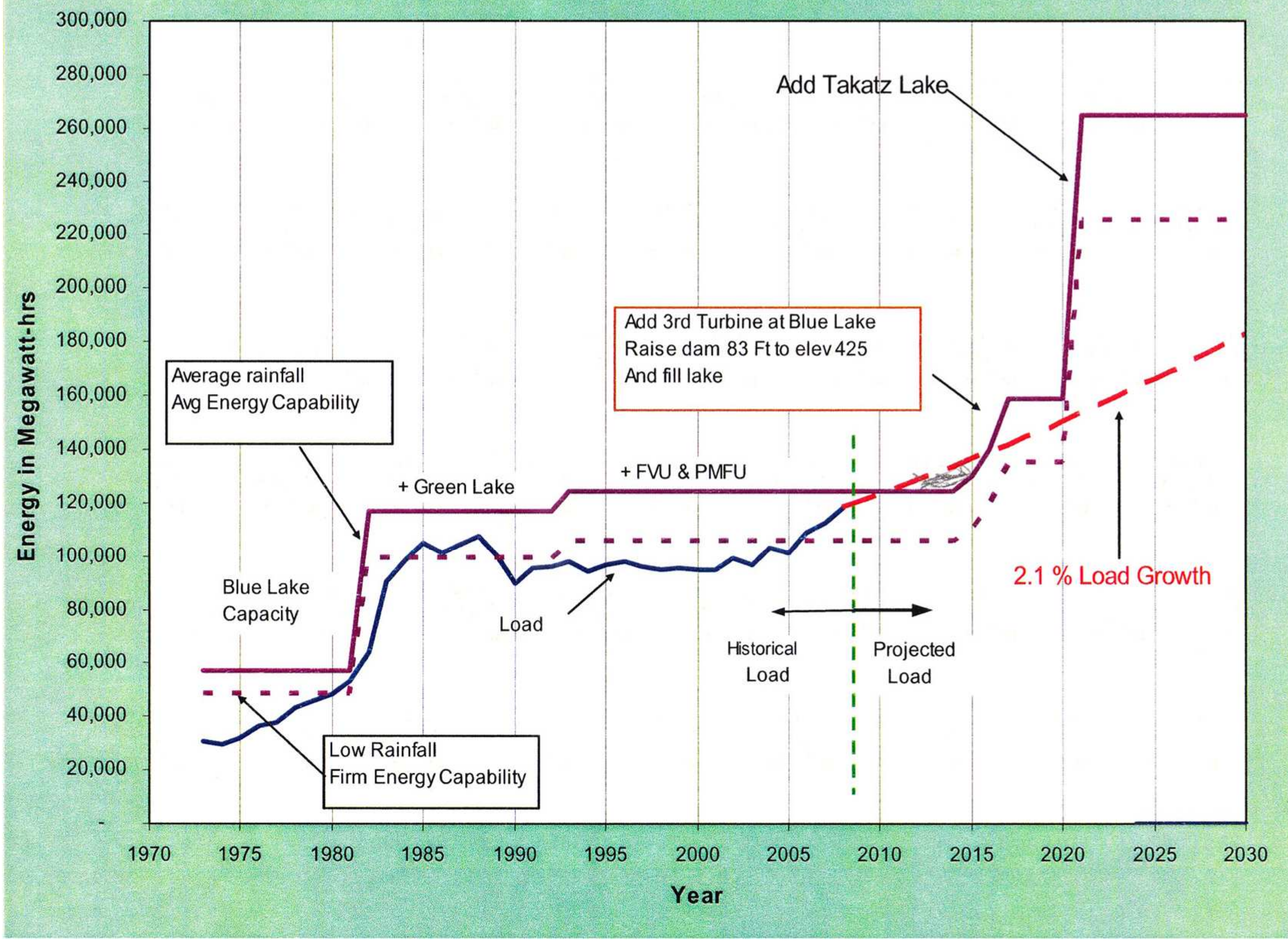
Scandinavian Electric Grid



Global Energy Network Institute

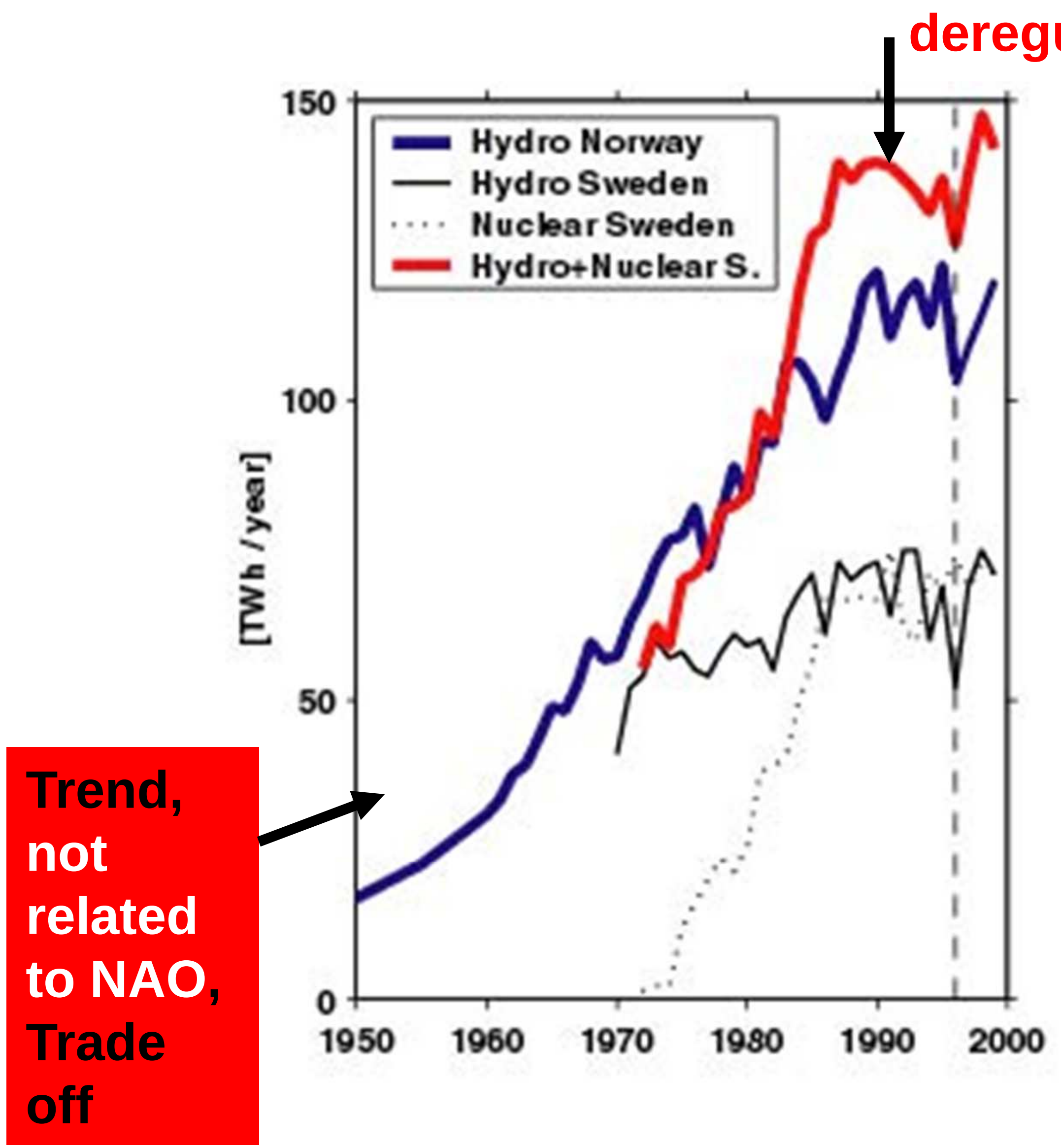
Climate Sensitivity of Hydropower Systems

Energy Requirement – 2.1%



SITKA Facilities, courtesy Chris Brewton

Energy production trends in Norway and Sweden

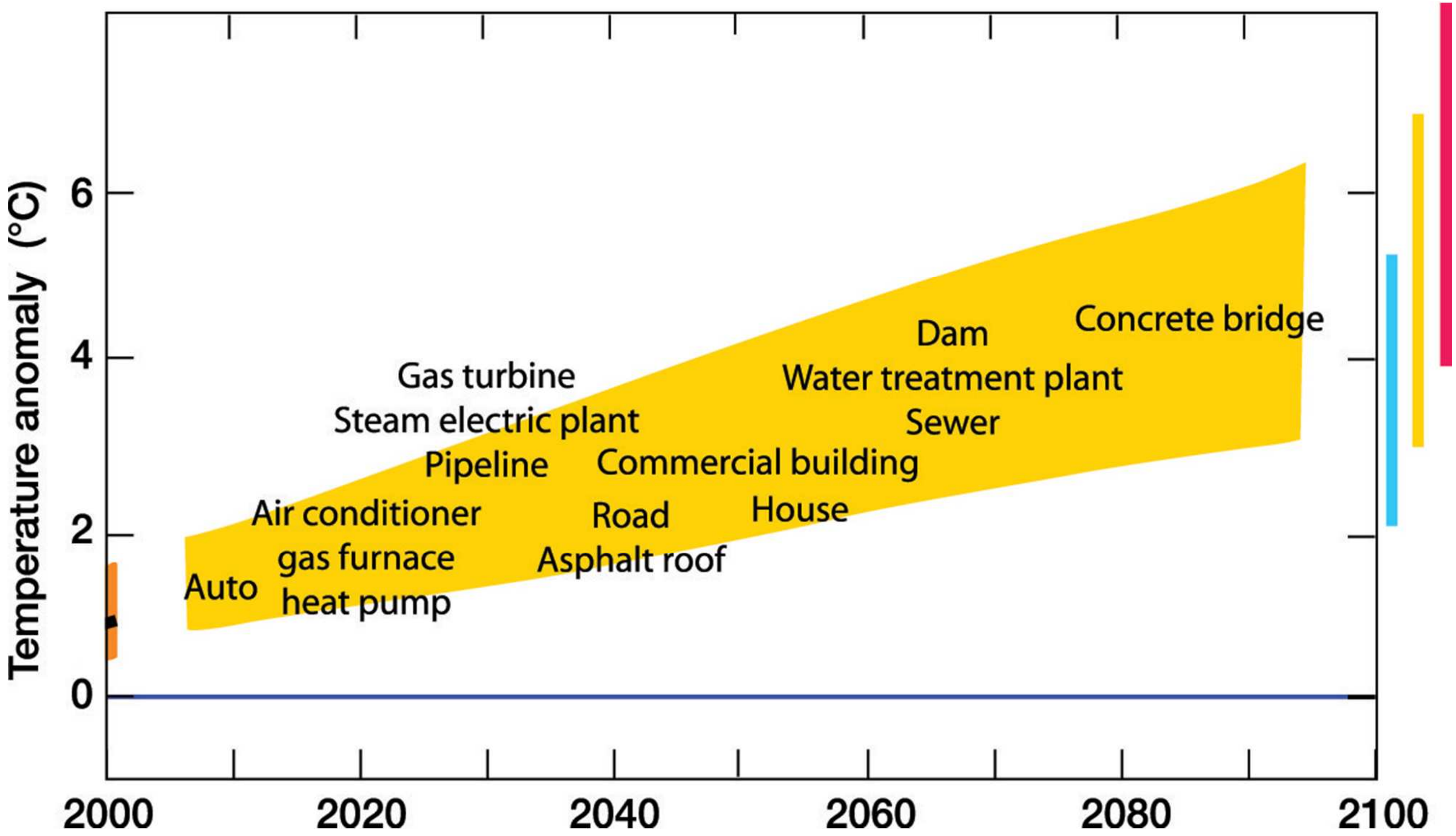


Energy supply in Norway and Sweden comes from only two sources, both which are climate dependent (directly or indirectly).

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

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

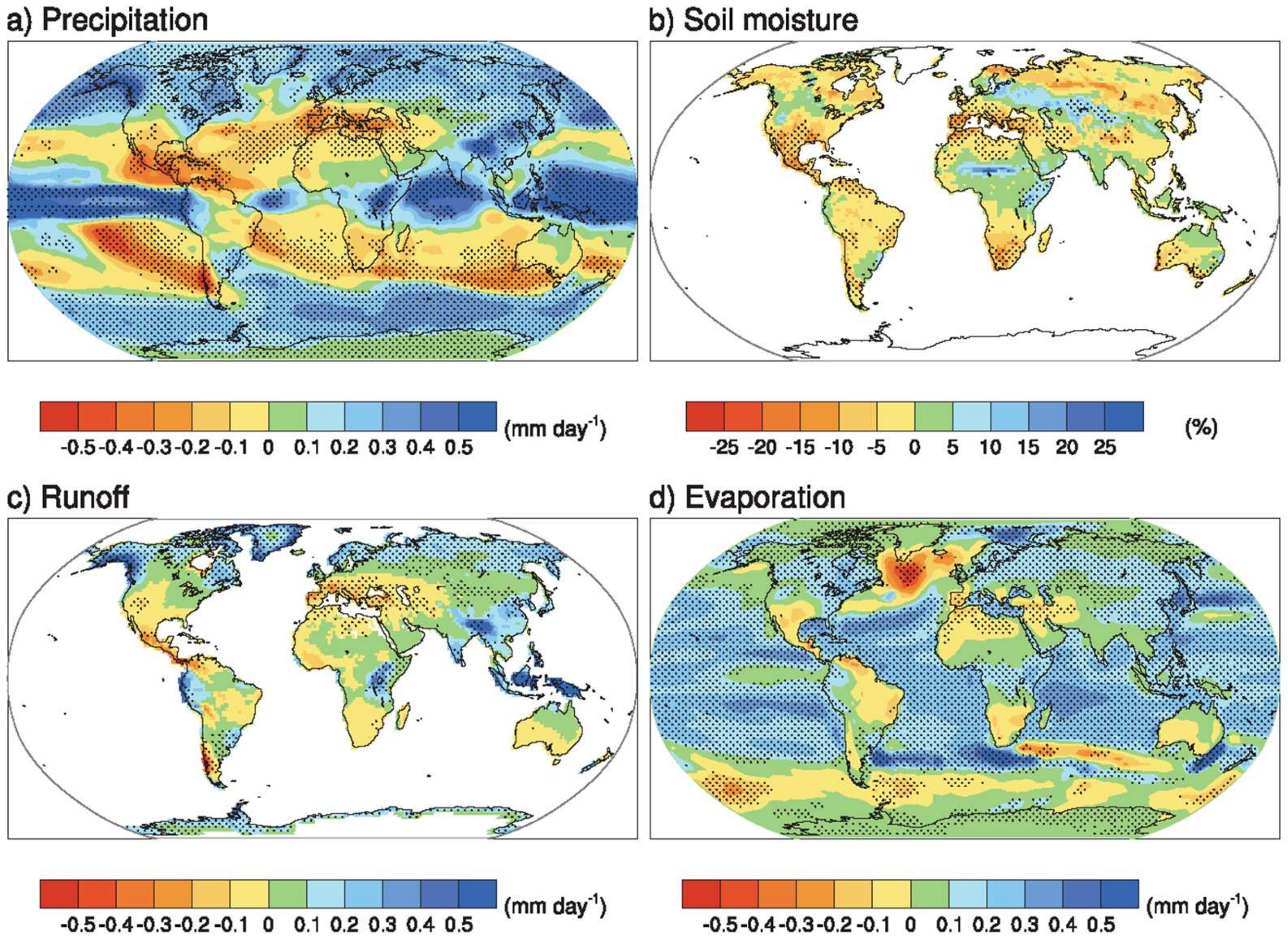
Projected temperatures and infrastructure lifespan



IPCC, 2007

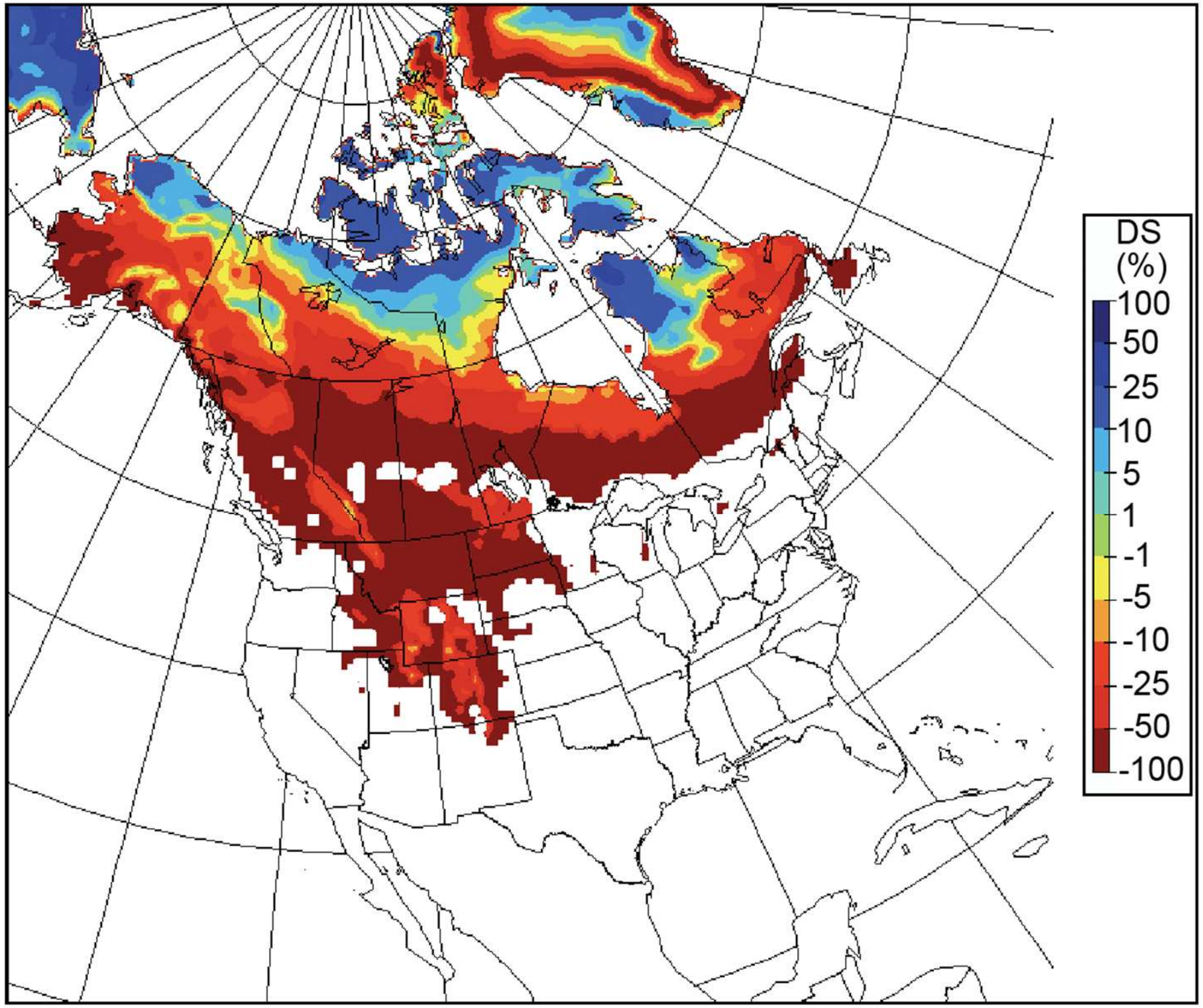
Long-term Climate Change Projections: good for hydropower

IPCC projected water cycle changes (missing permafrost, glacier feedbacks)



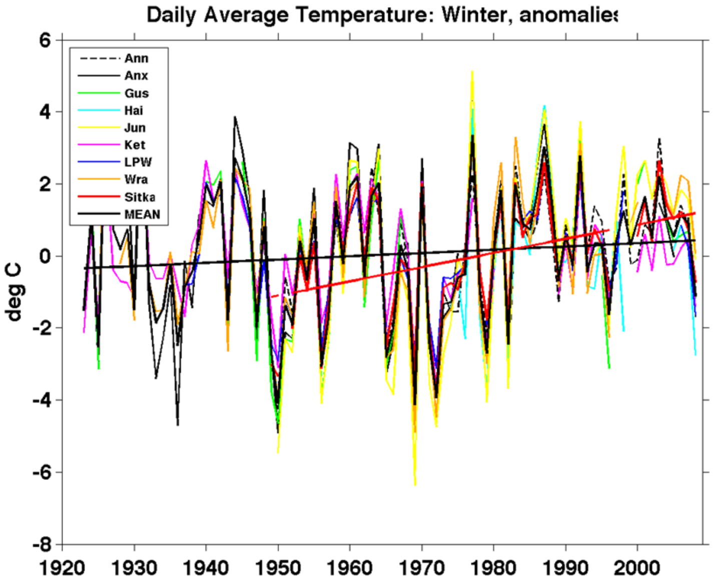
Meehl et al., 2007

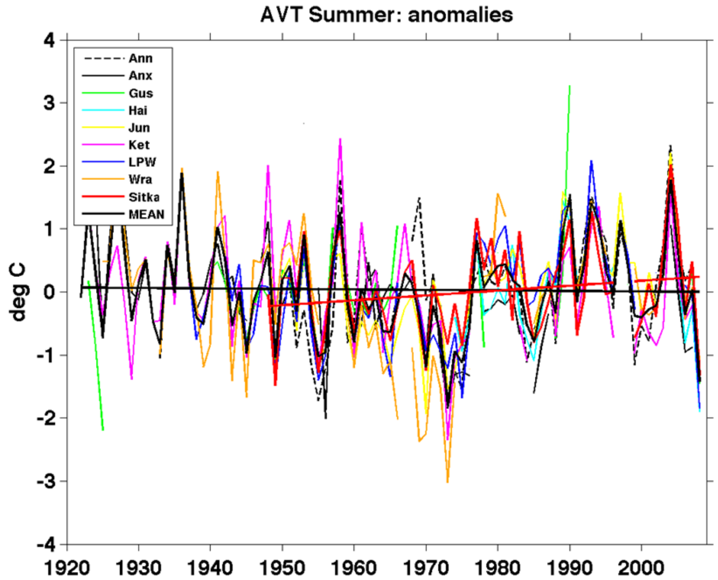
Projected spatial snow cover change

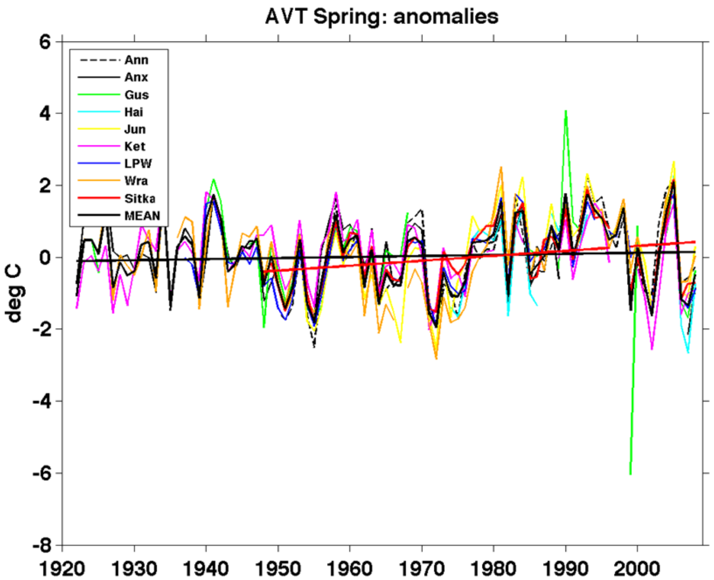


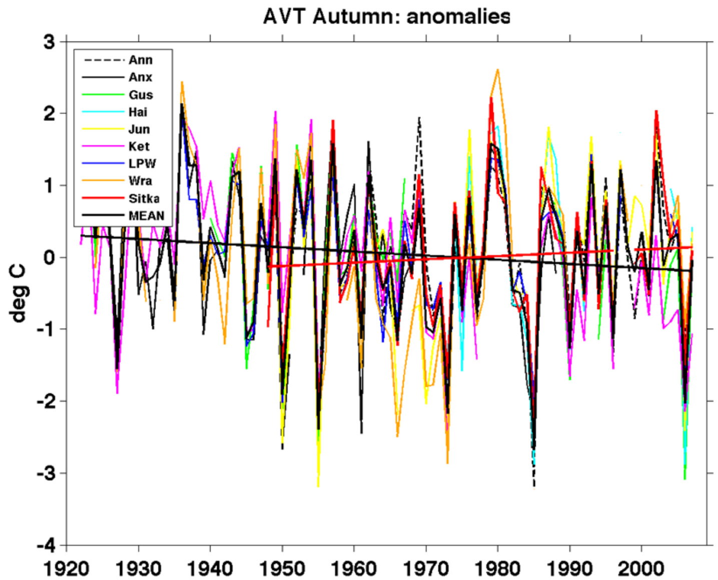
IPCC AR4, 2007

Observed Historical Average Temperature Anomalies by Season for SEAK

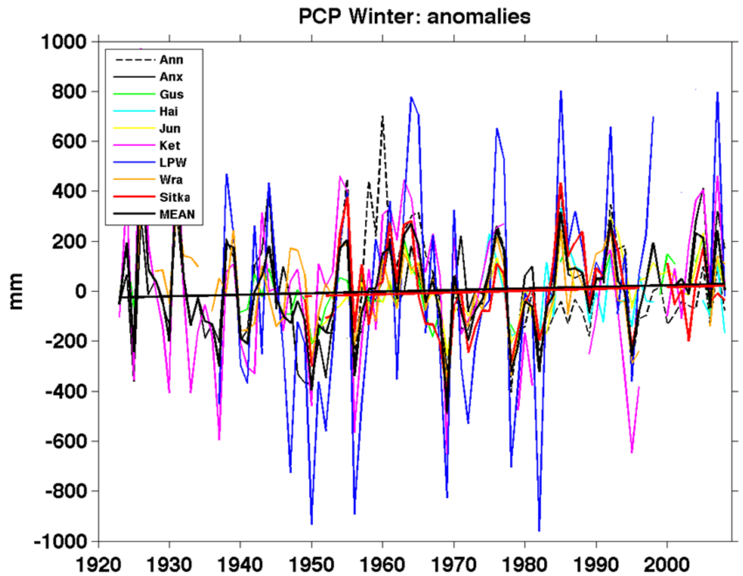


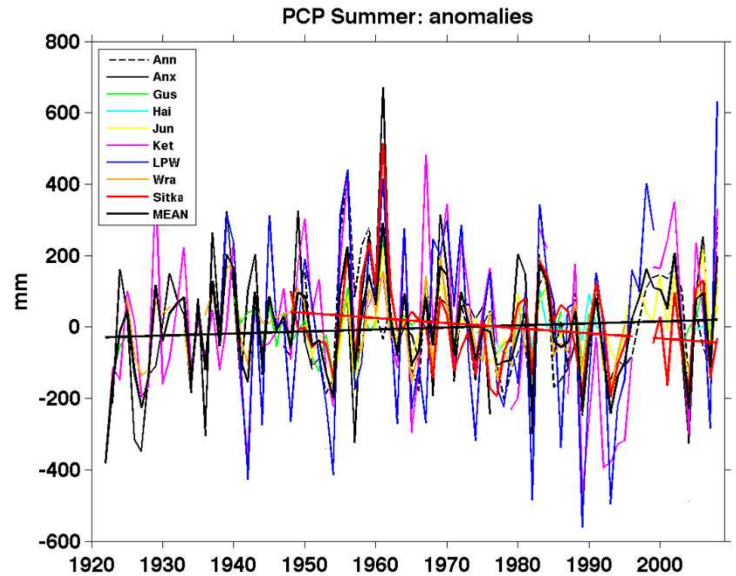


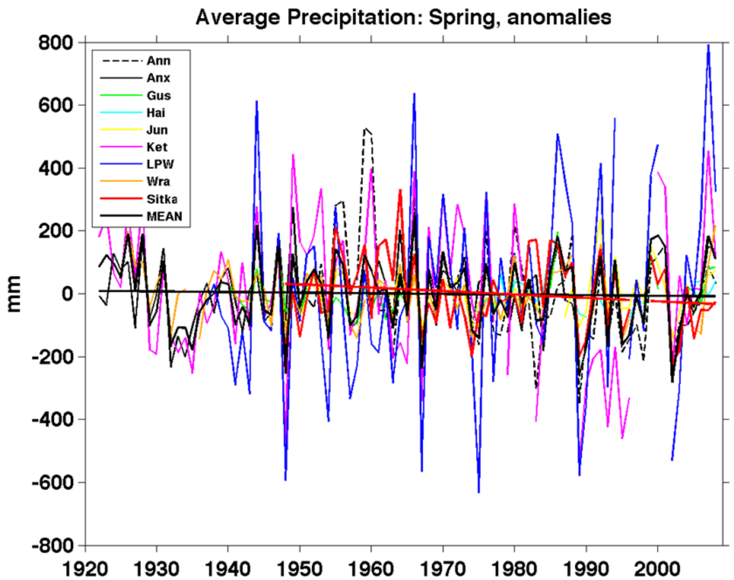


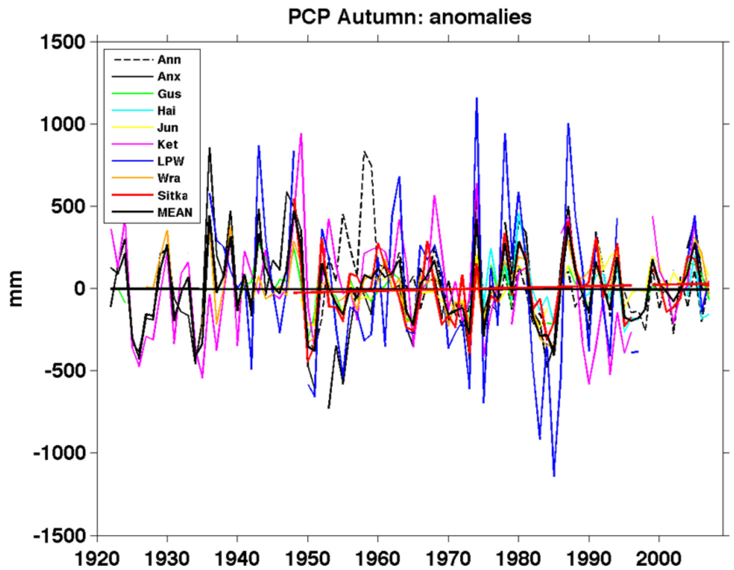


Observed Historical Precipitation Anomalies by Season for SEAK



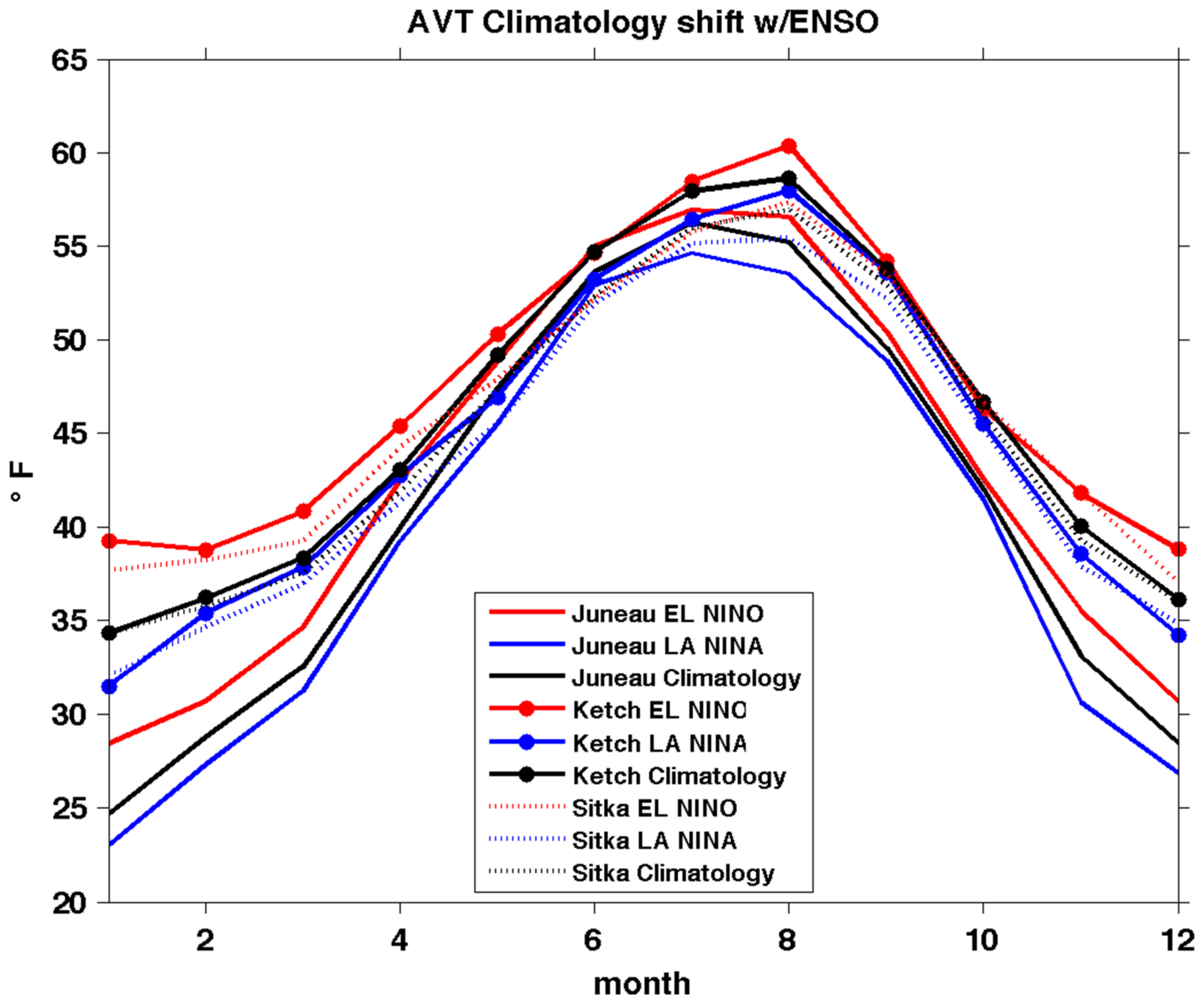




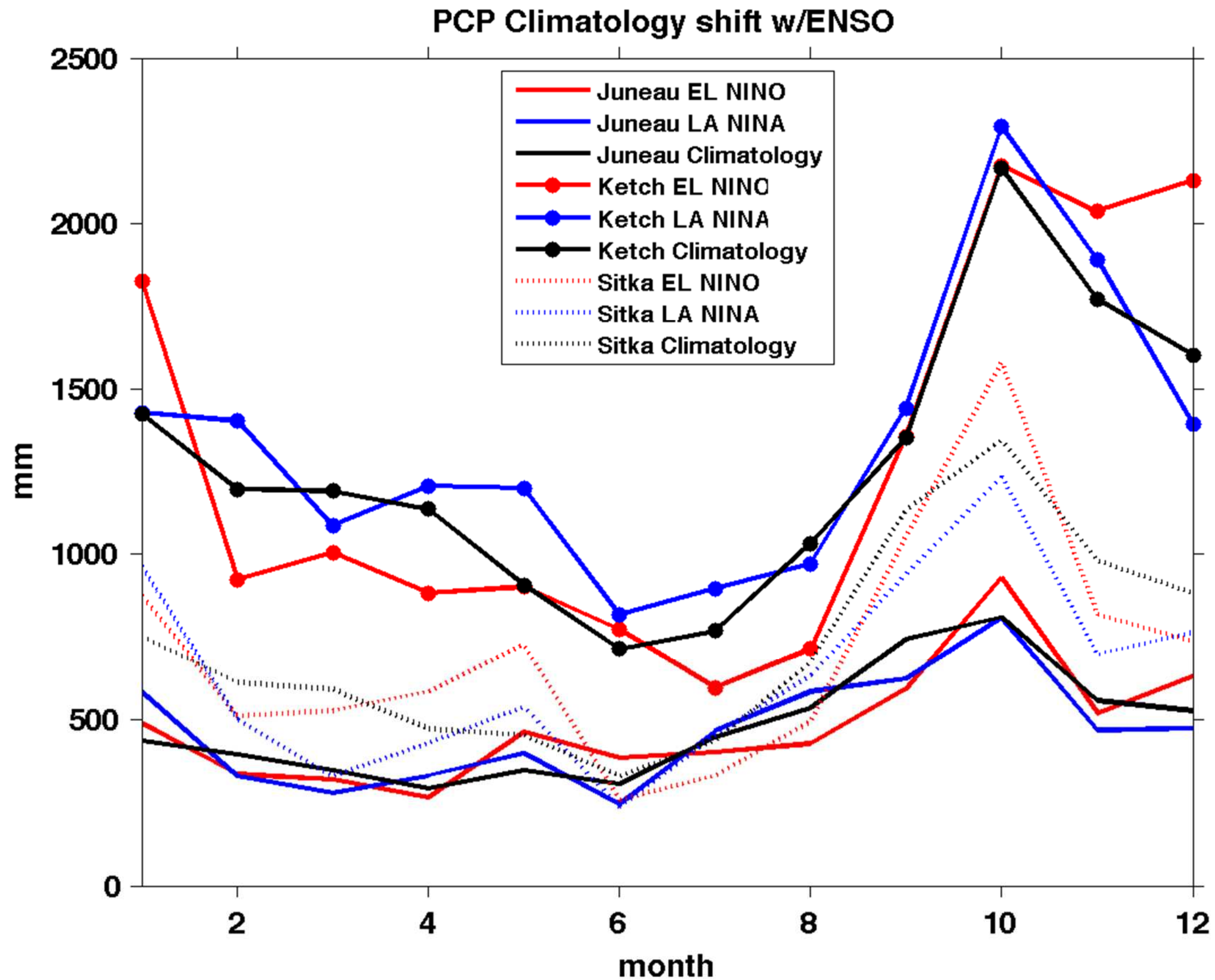


Climate Variability:
working on multiple scales

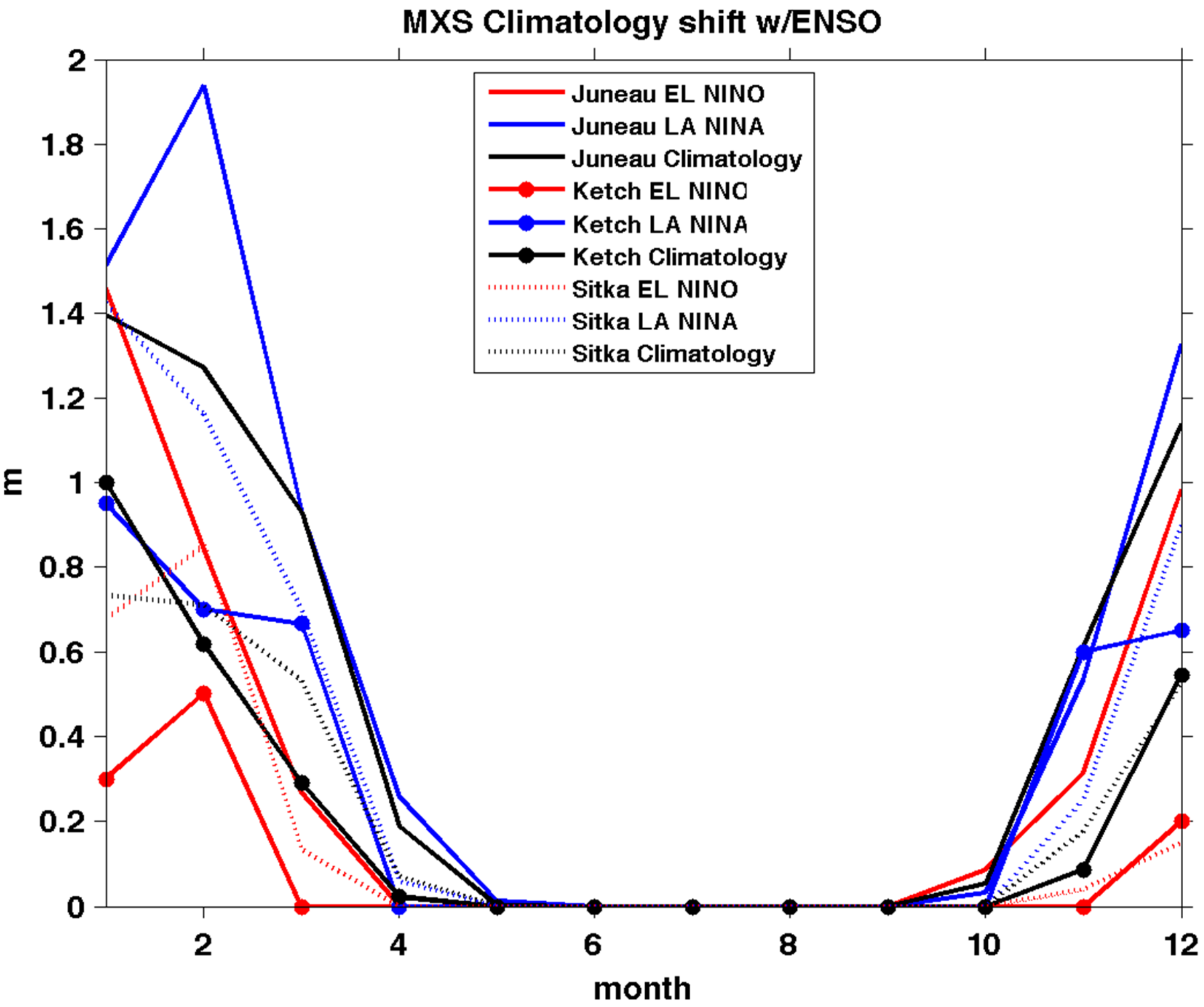
Impact of ENSO at SEAK Stations



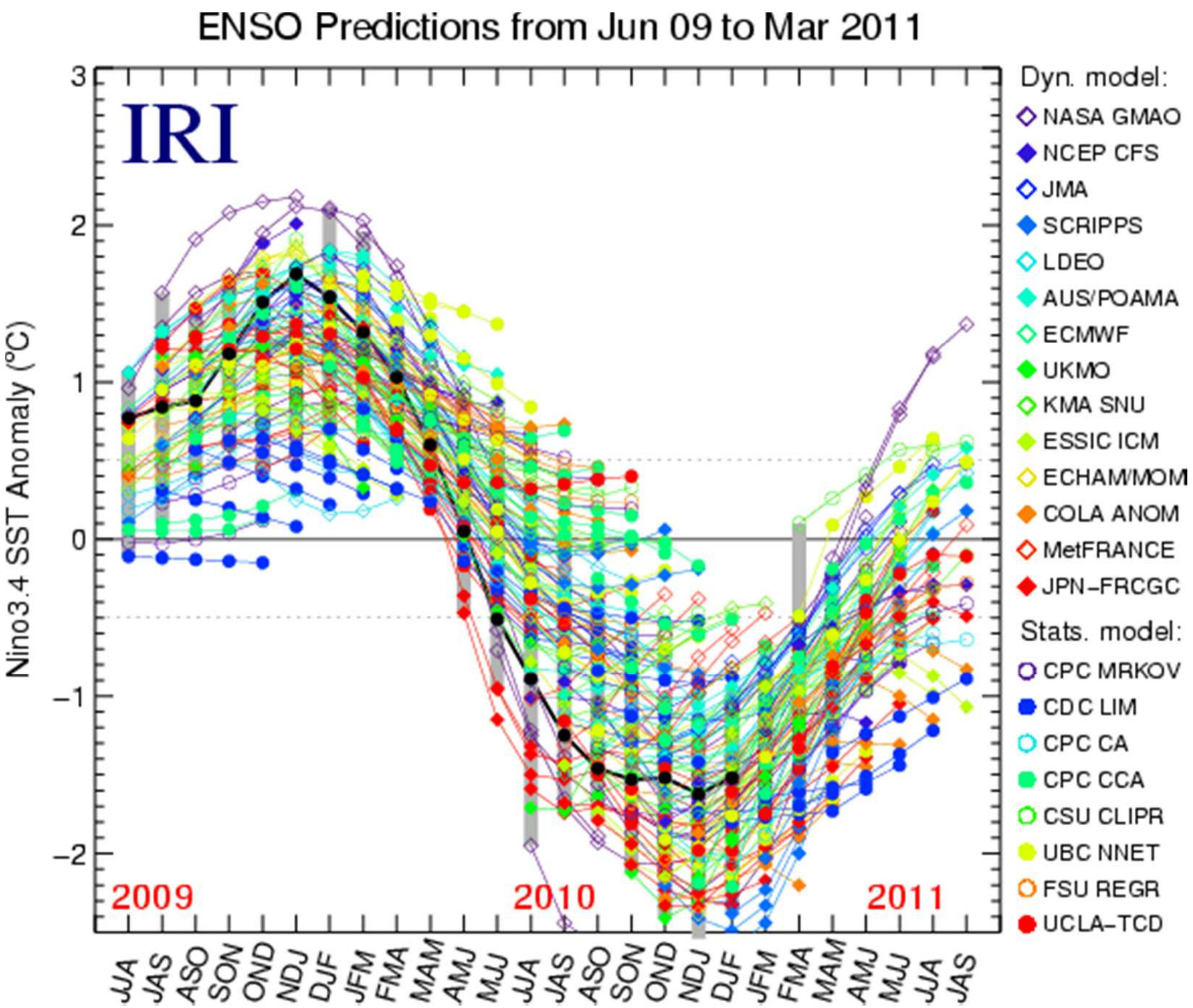
Impact of ENSO at SEAK Stations



Impact of ENSO at SEAK Stations

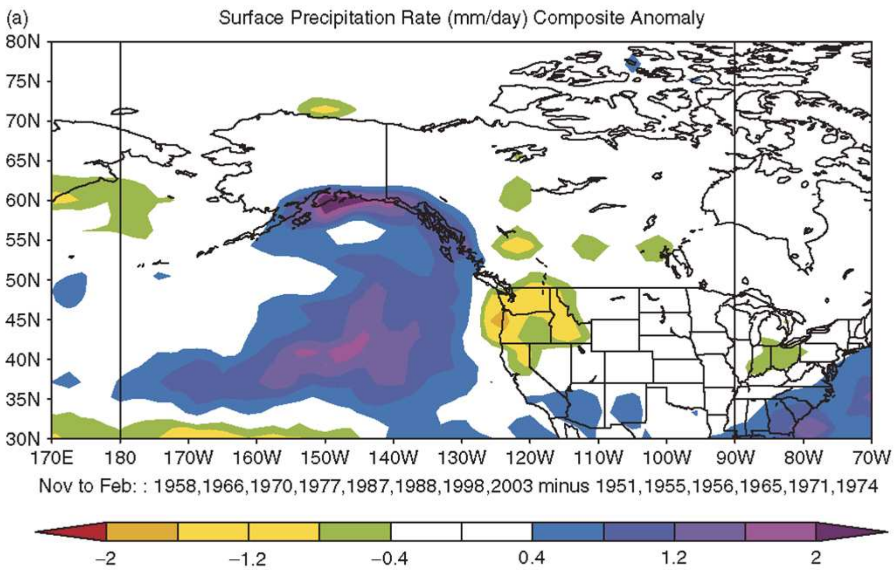


Predictability of ENSO

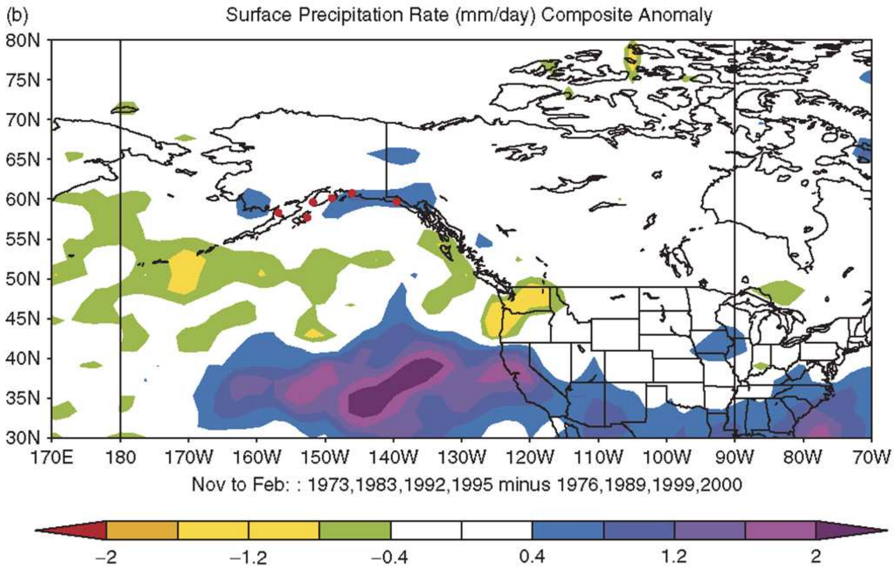


Difference Plots: precipitation

ElNino/AO-
minus
LaNina/AO-



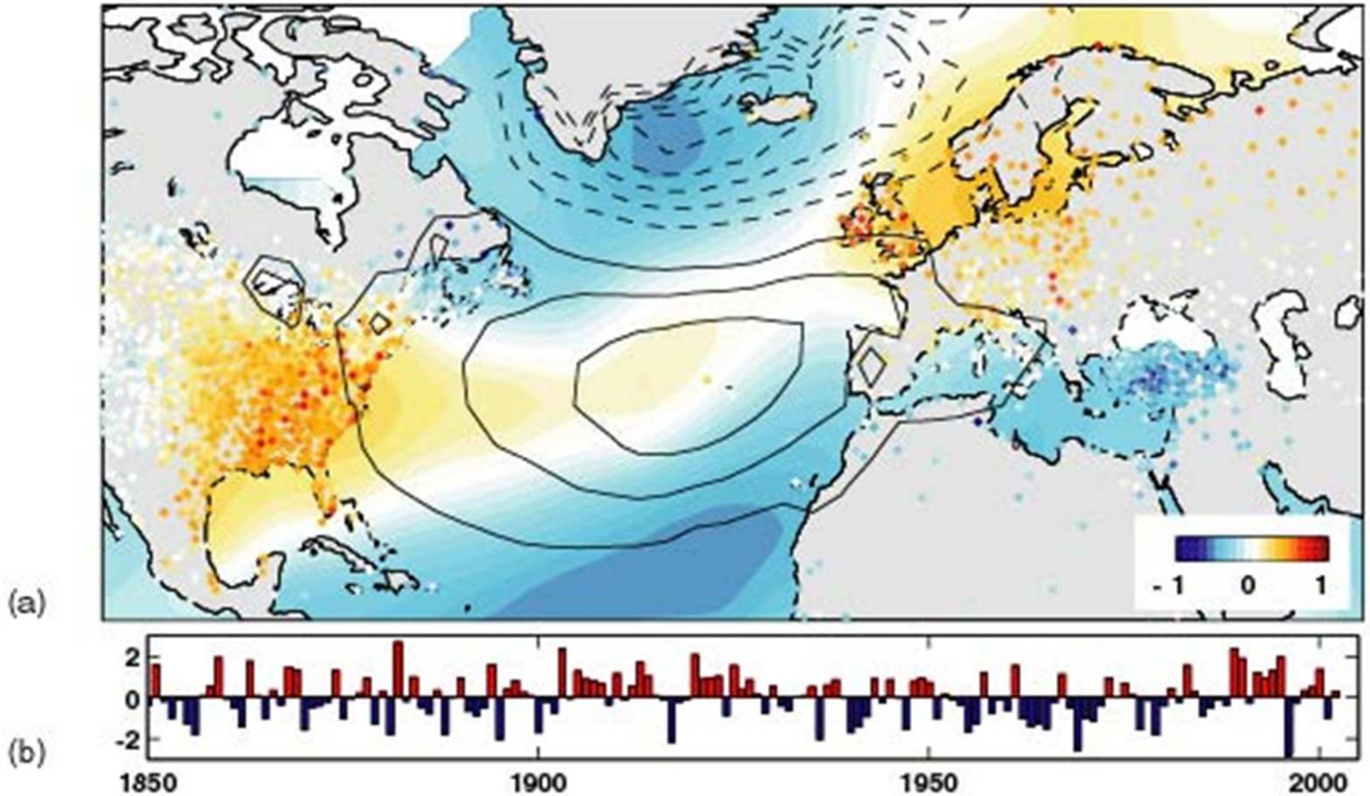
ElNino/AO+
minus
LaNina/AO+



Bond and
Harrison, 2006

Physical Impacts of the NAO

data



NAO Index is the highly correlated with climate fields

NAO Index (Jones 1997) and :

correlation with DJFM SST (Kaplan et al 1998)

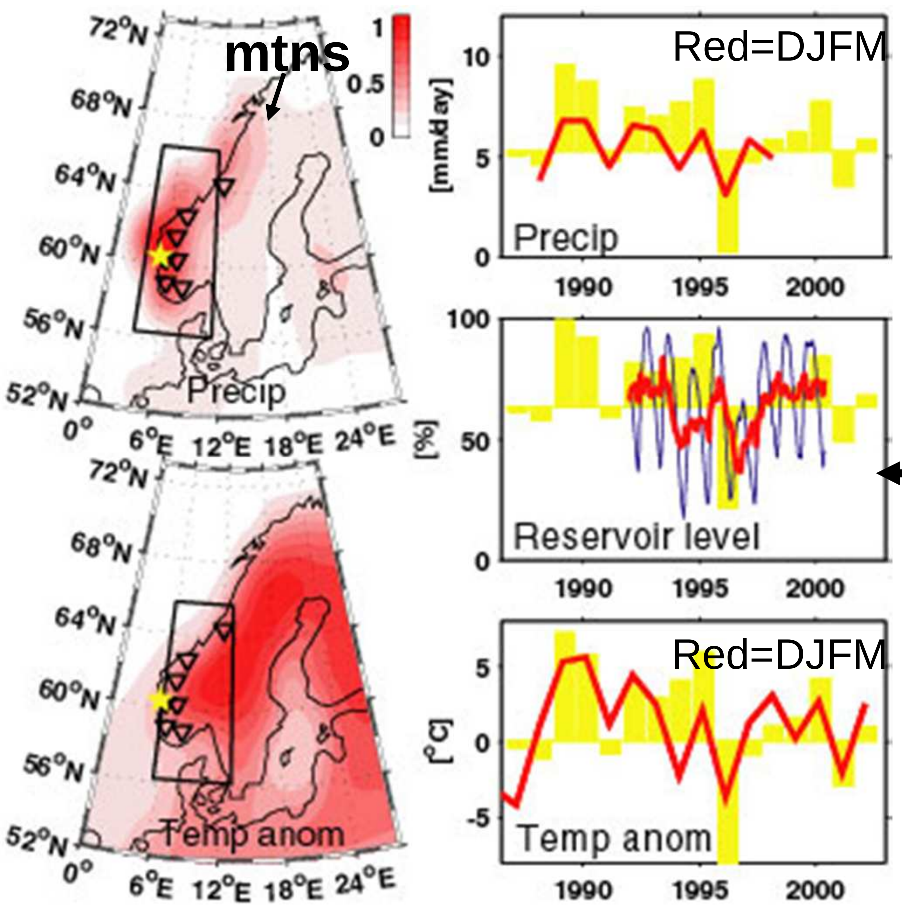
correlation with DJFM SAT (NCDC/GHCN)

covariance with DJFM SLP at 0.3 HPa contour intervals (NCEP reanalysis)

Trends:
upward?
persistent?

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



PCs

EOFs

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

(Red=annual mean+weekly level-seasonal cycle)

☆ = Bergen, will use this from now on

▽ = Major reservoirs

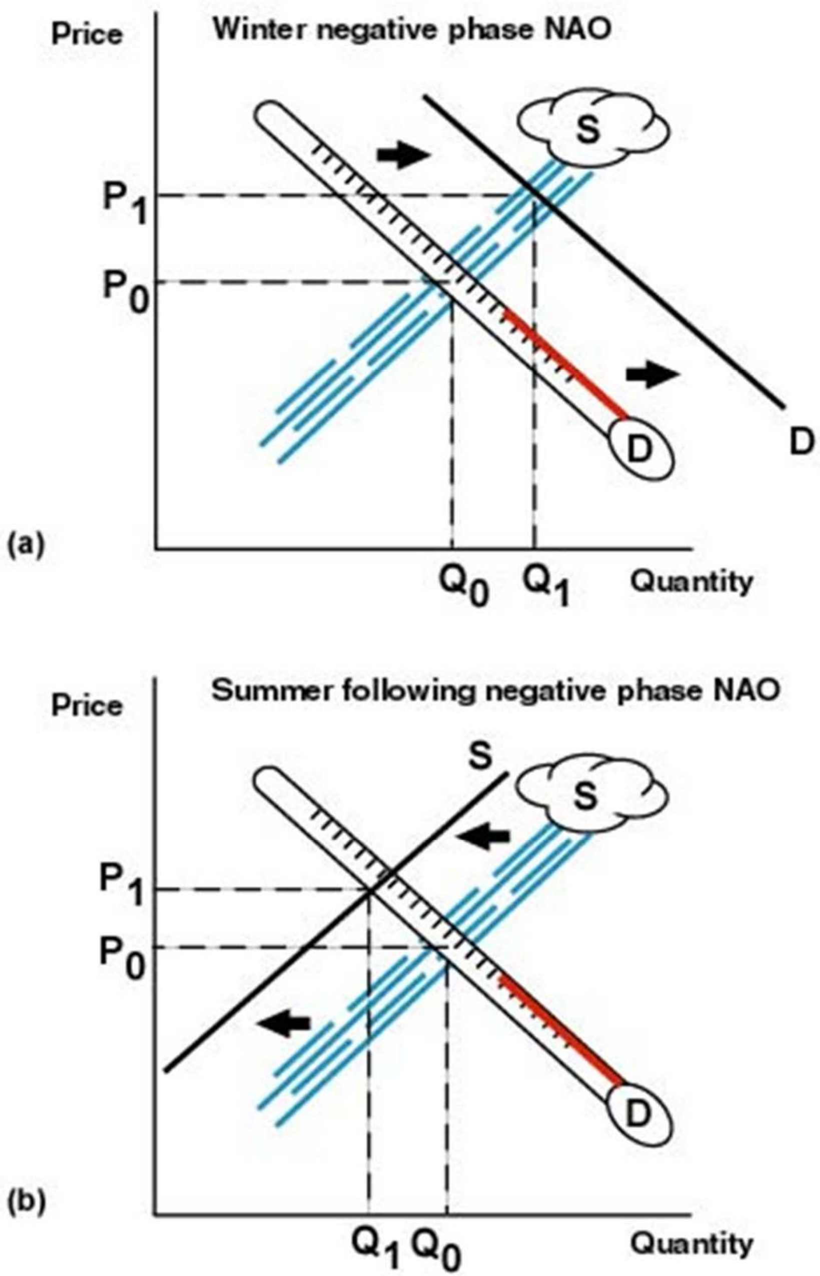
Data: Xie & Arkin, NCEP, Statistics Norway

Market Setting

The 1996-1997 event

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

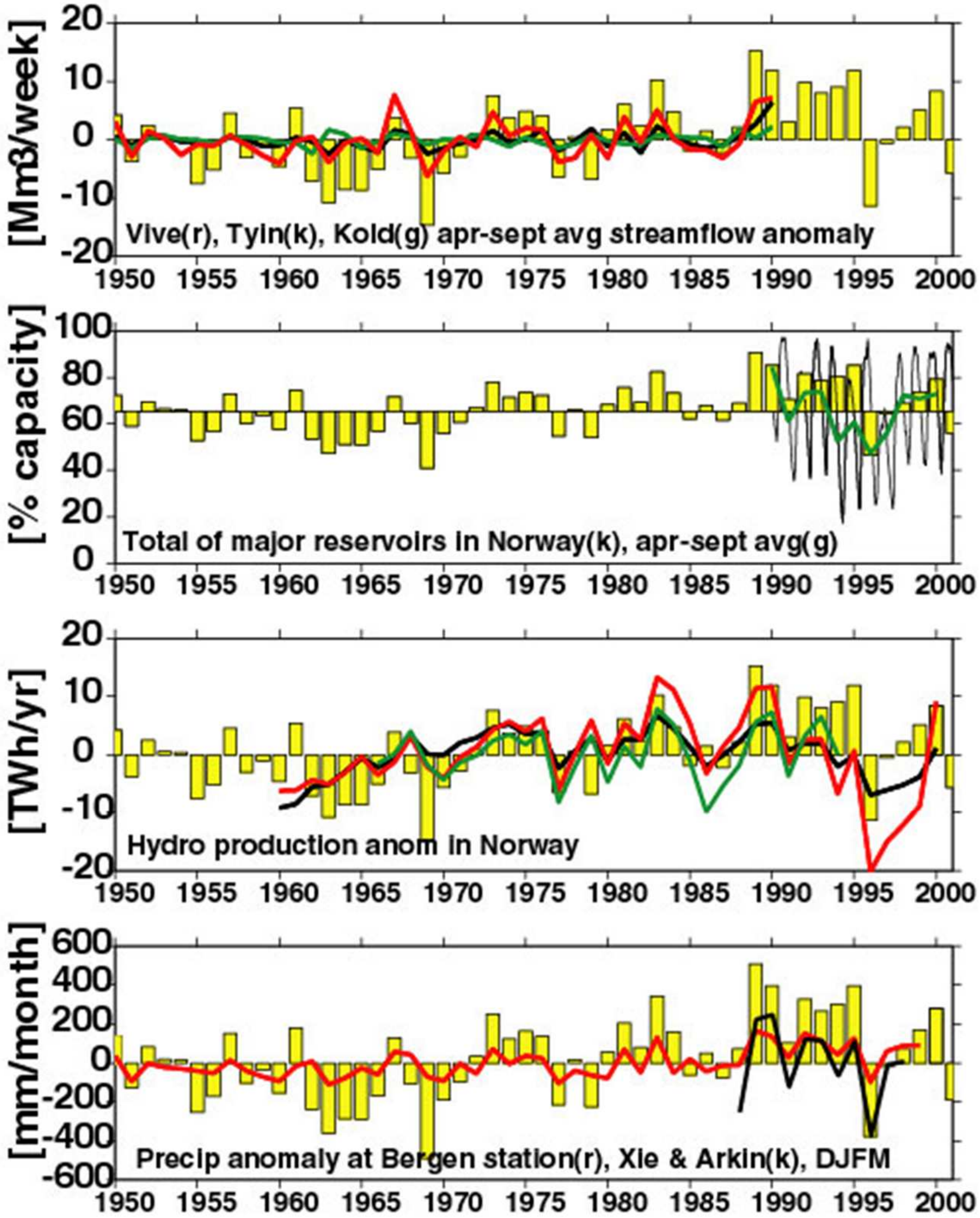
r =+0.6

Hydropower production anomaly

r ~+0.5

Precipitation anomaly (1994-5 off)

r =+0.8

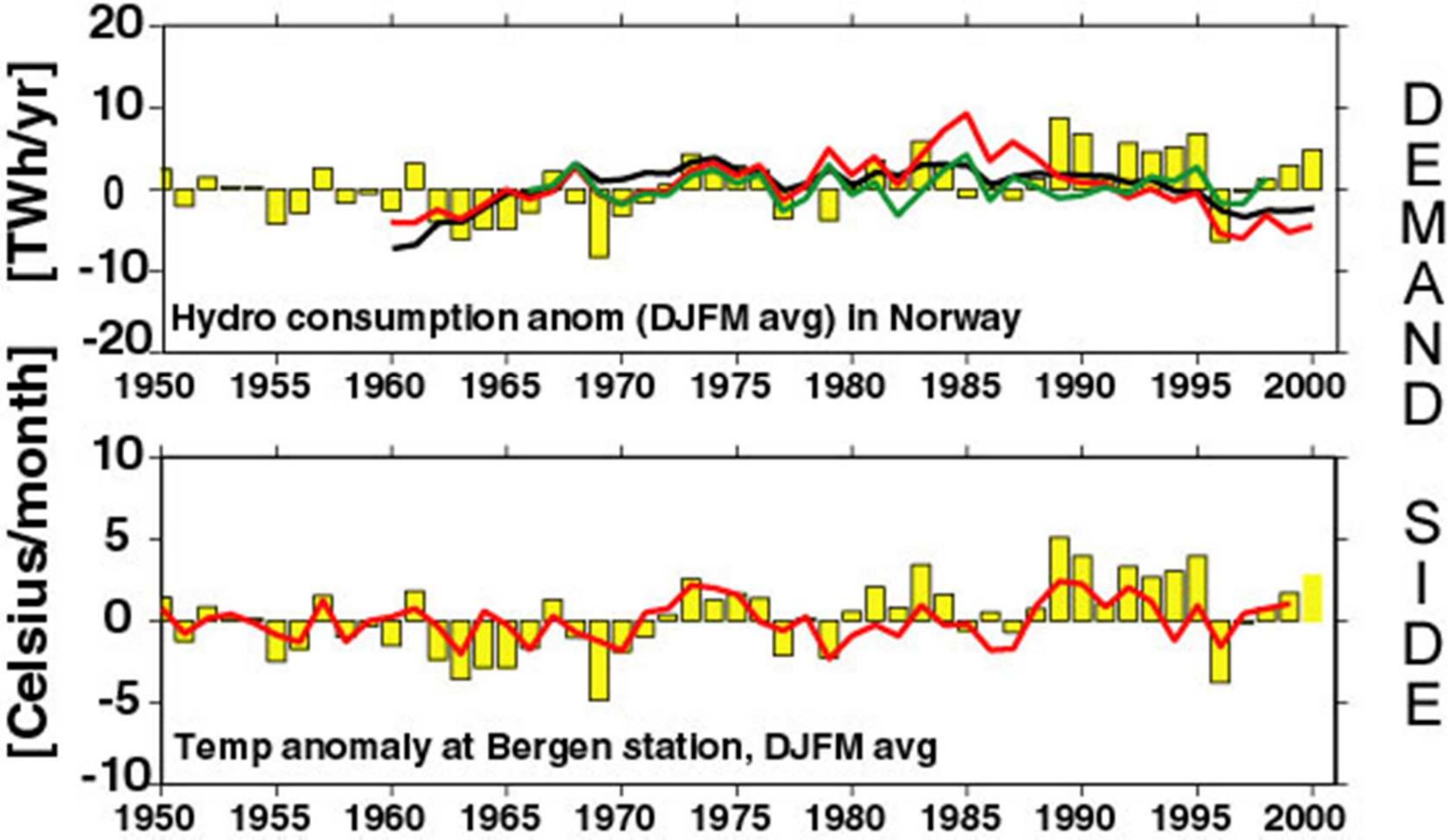


SUPPLY SIDE

Hydropower consumption anomaly

→

r ~ - 0.5



Temperature anomaly

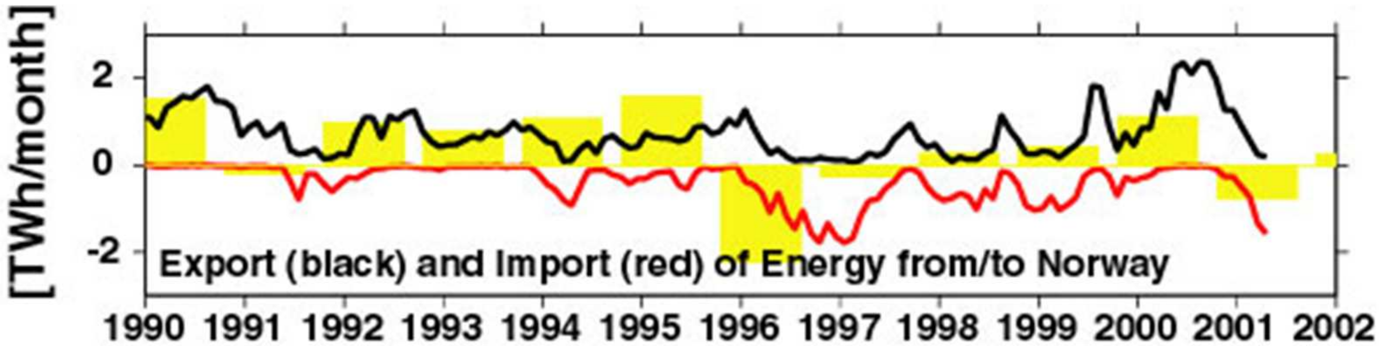
→

r = 0.7

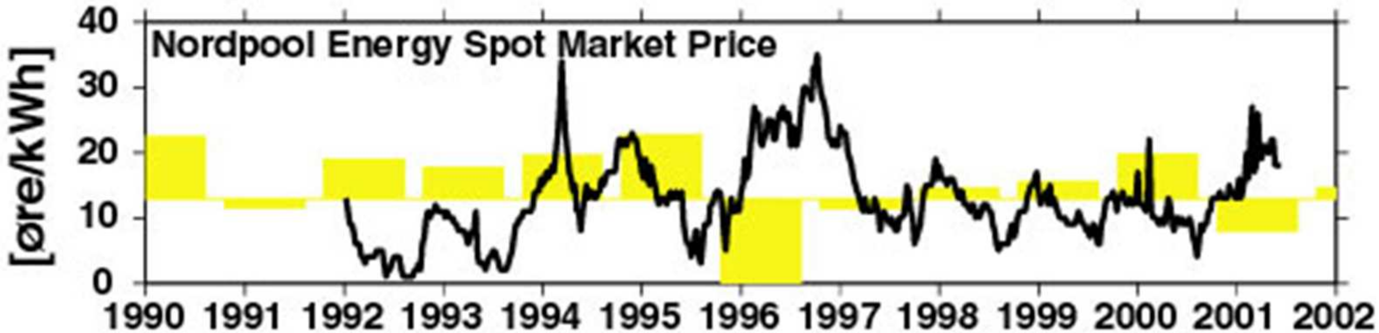
1994-1995 off

Deregulation and privatization in the 1990s allowed the establishment of the first international market for energy derivatives, called Nordpool.

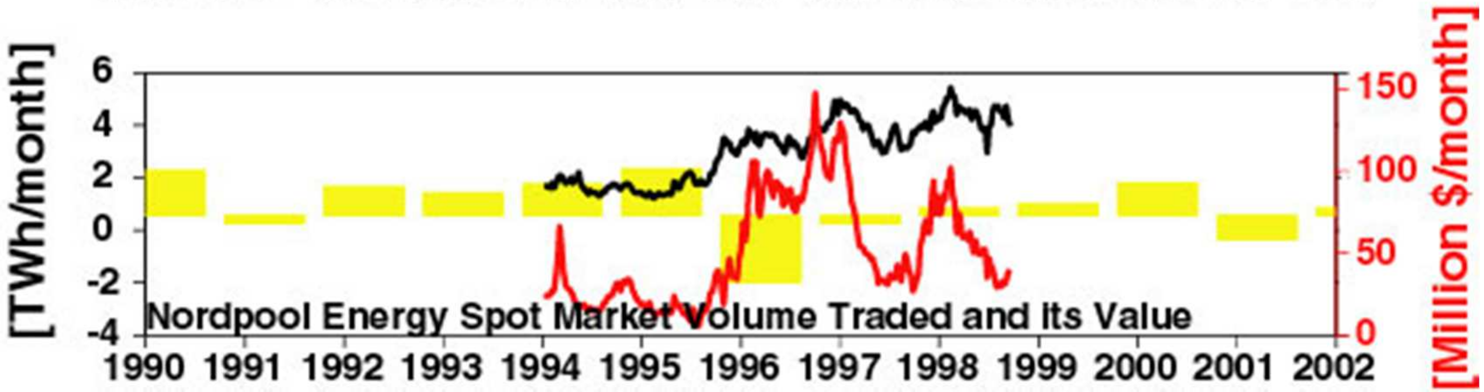
Electricity trade in Norway



Electricity spot market price



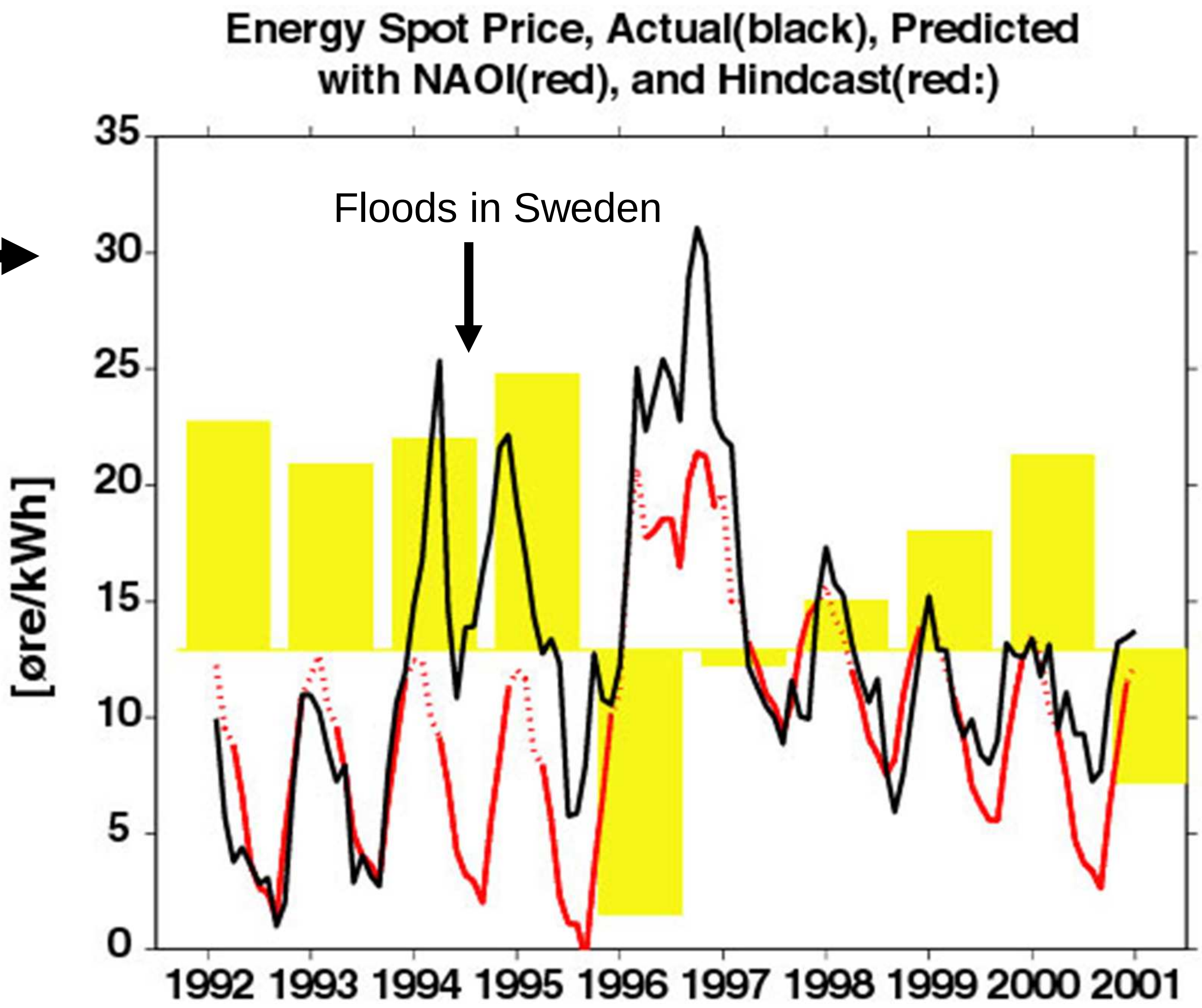
Spot volume traded and its value in dollars

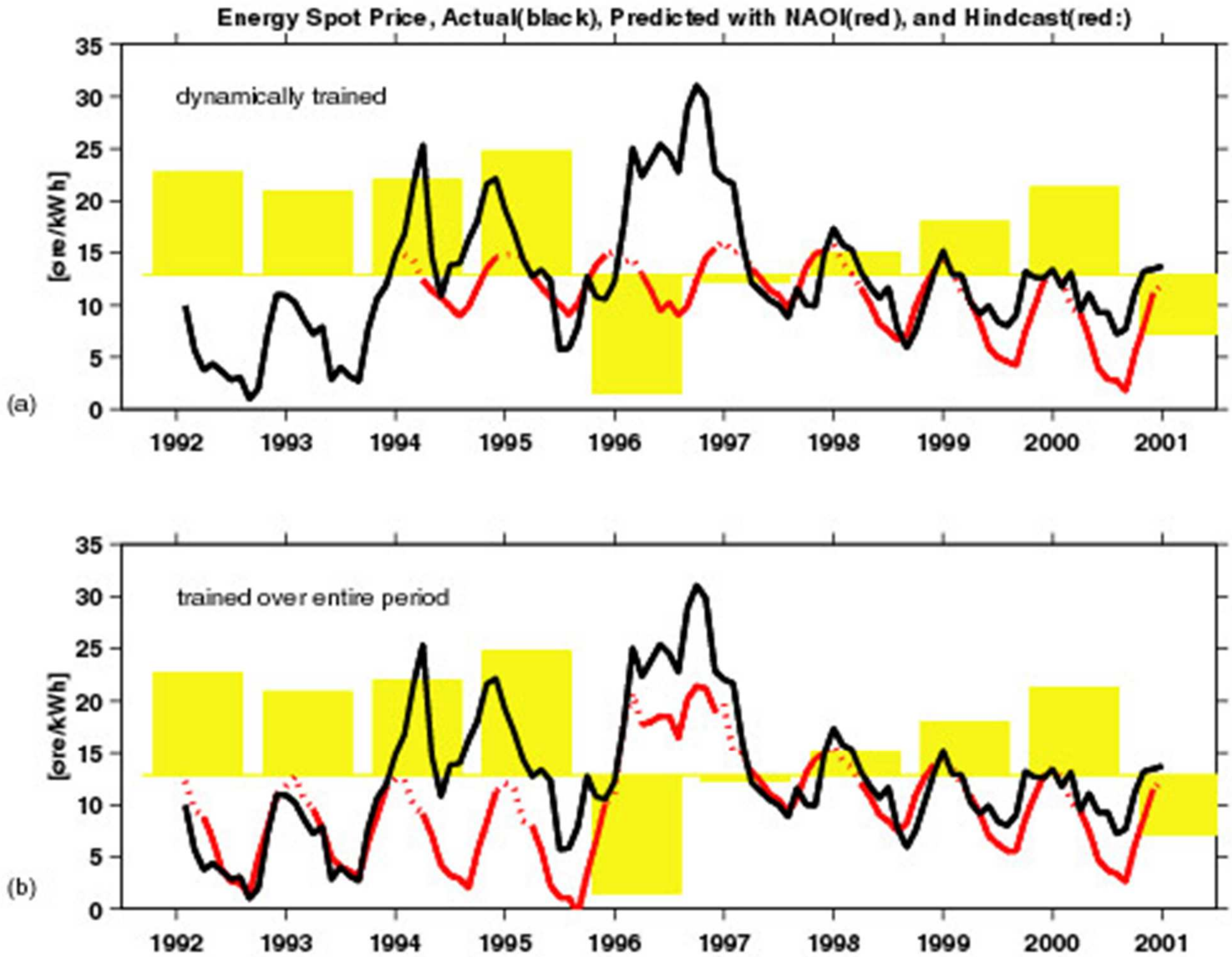


Correlation tests seem to support the proposed mechanism. Can the NAO Index then be used to predict spot prices?

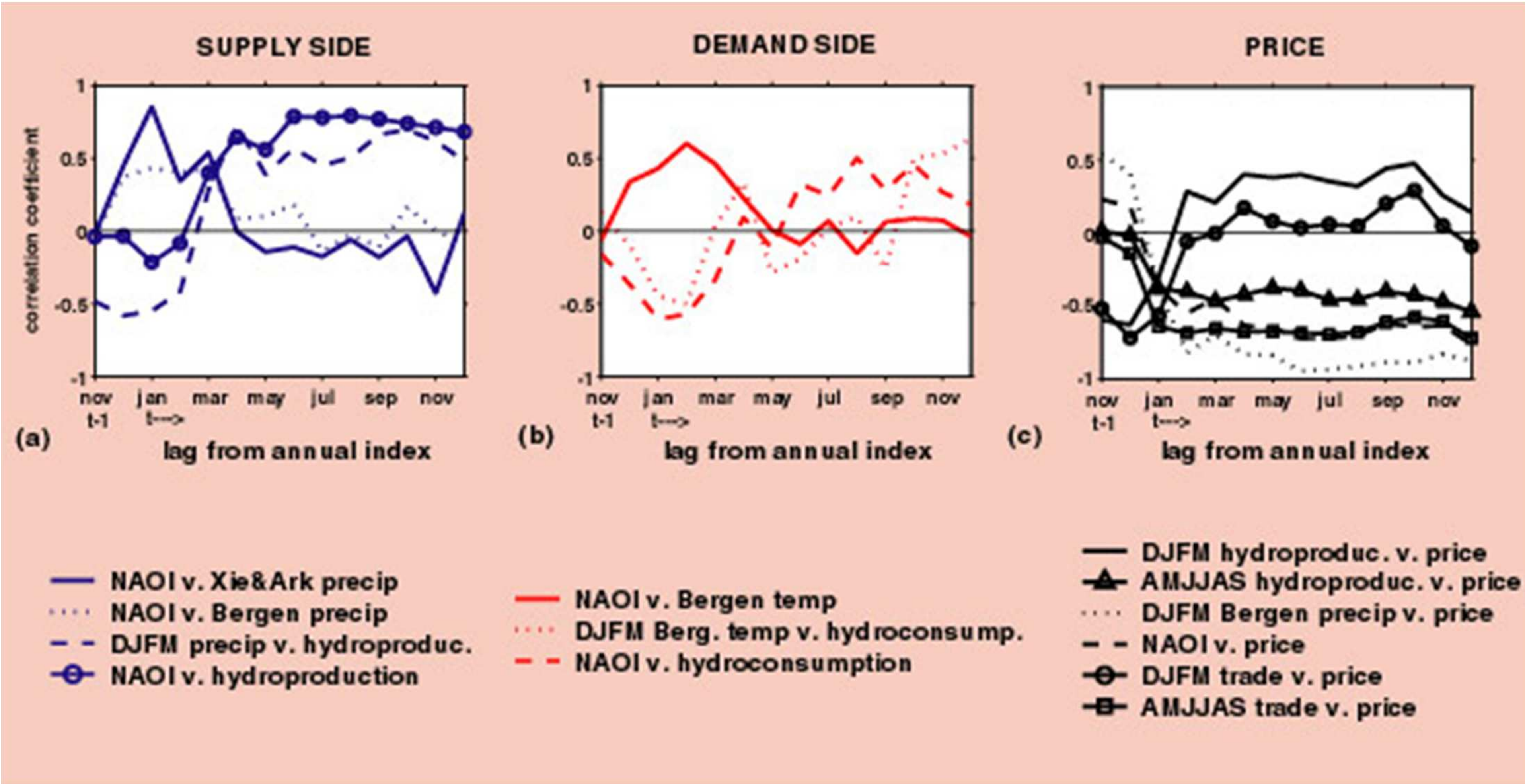
Prices predicted solving Ax=b by regression

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





Energy Spot Price, Actual(black), Predicted with NAOI(red), and Hindcast(red:)
dynamically trained
[ore/kWh]
(a)
35
30
25
20
15
10
5
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
trained over entire period
[ore/kWh]
(b)



SUPPLY SIDE
DEMAND SIDE
PRICE
correlation coefficient
1
0.5
0
-0.5
-1
nov t-1
jan t--->
mar
may
jul
sep
nov
(a)
(b)
(c)
lag from annual index
NAOI v. Xie&Ark precip
NAOI v. Bergen precip
DJFM precip v. hydroproduc.
NAOI v. hydroproduction
NAOI v. Bergen temp
DJFM Berg. temp v. hydroconsump.
NAOI v. hydroconsumption
DJFM hydroproduc. v. price
AMJJAS hydroproduc. v. price
DJFM Bergen precip v. price
NAOI v. price
DJFM trade v. price
AMJJAS trade v. price

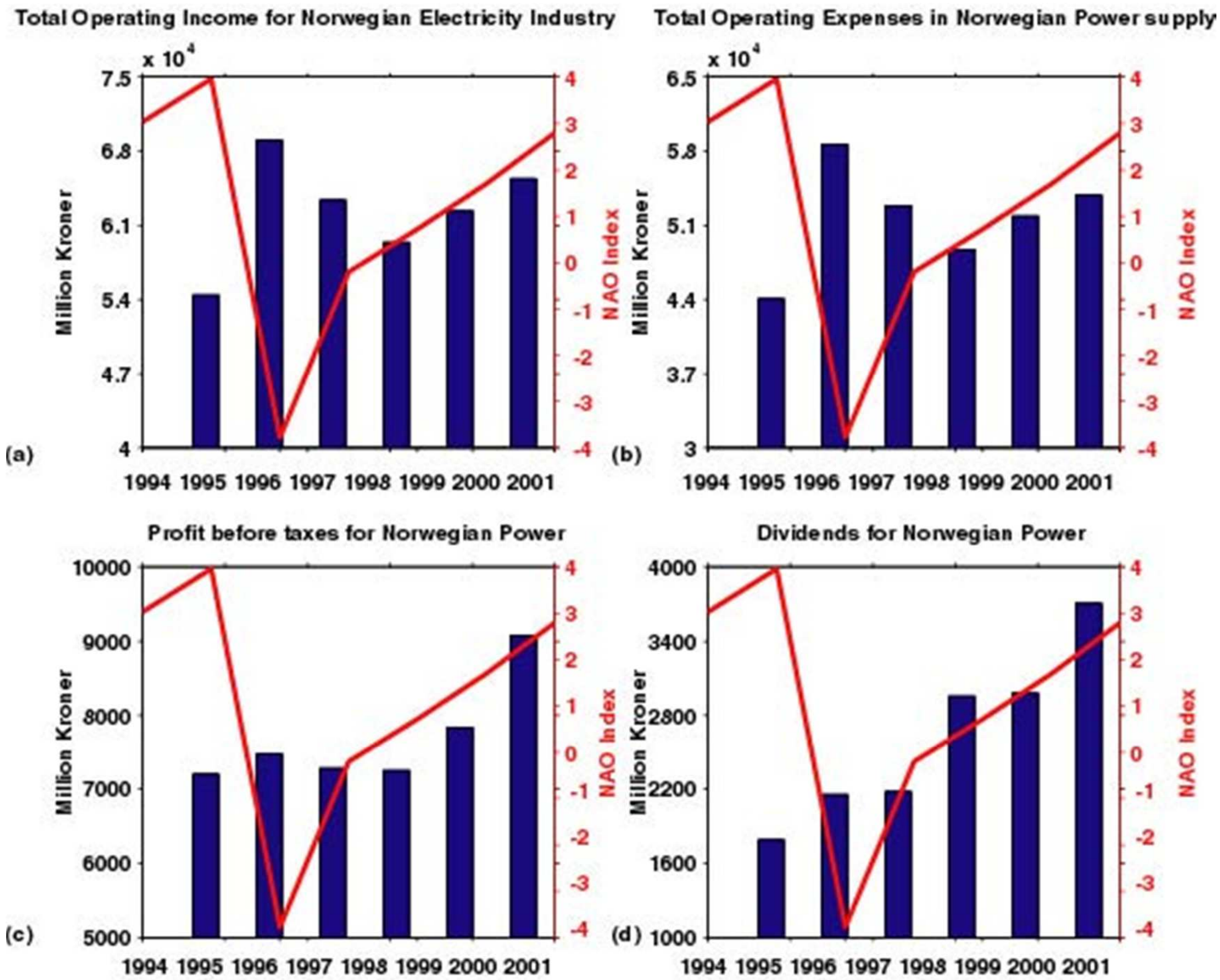


Figure 10a-f: Financial figures regarding the hydropower sector in Norway ploted against the NAO Index.

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

In Norway, monitoring the snowpack is a management tool. SE doesn’t use snowpack monitoring.

Lessons for Susitna:

Regional Market Integration matters

Climate mechanisms matter…especially the potential for tipping points such as change in glacier distribution

The tools already exist to improve risk management considerably; need more training in use of seasonal forecasting

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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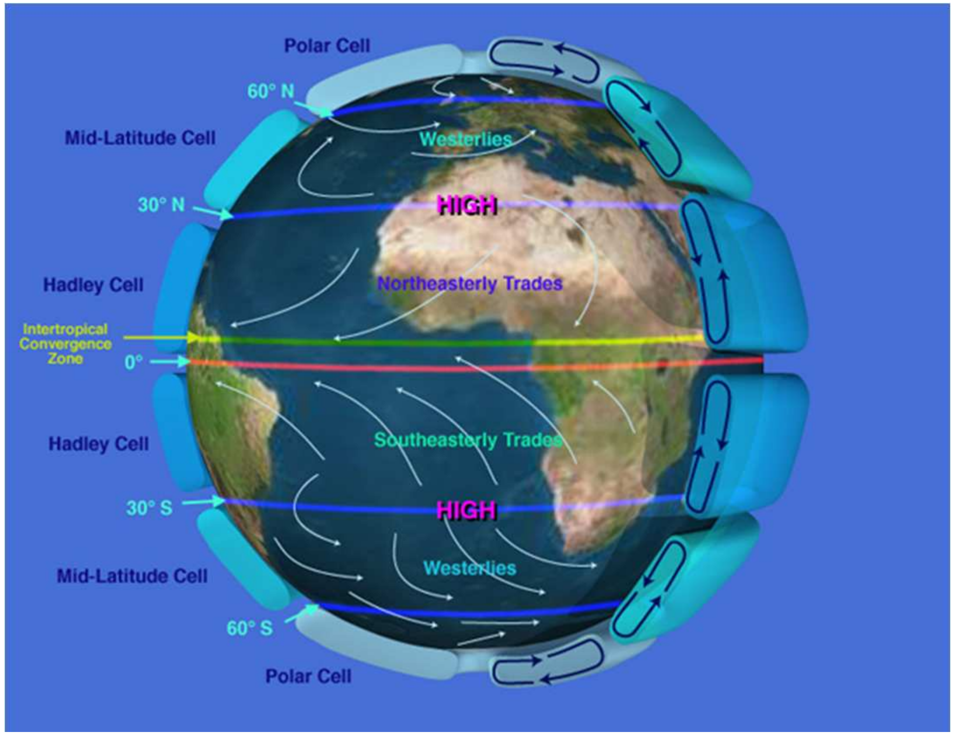
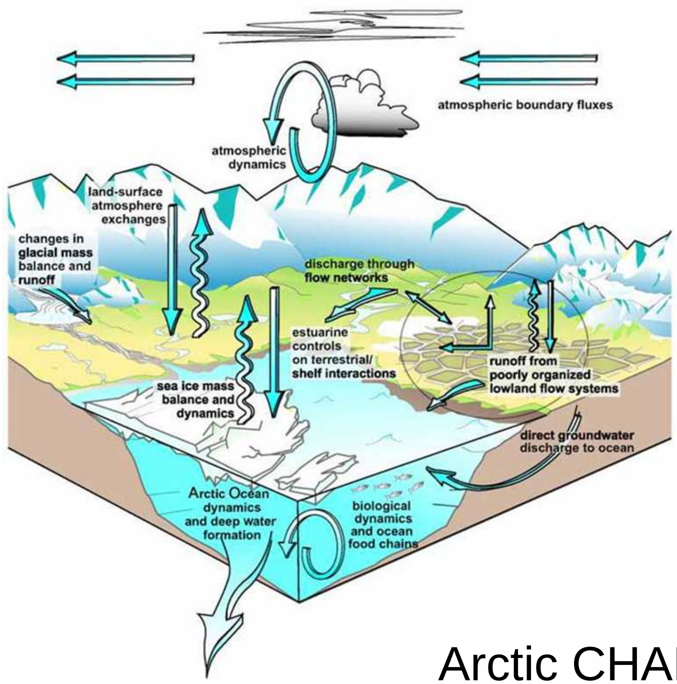
- Climate drivers in Alaska and the Arctic and how they impact hydropower
  - Large scale global ocean atmosphere circulation



Talking Points

- 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)



Arctic CHAMP

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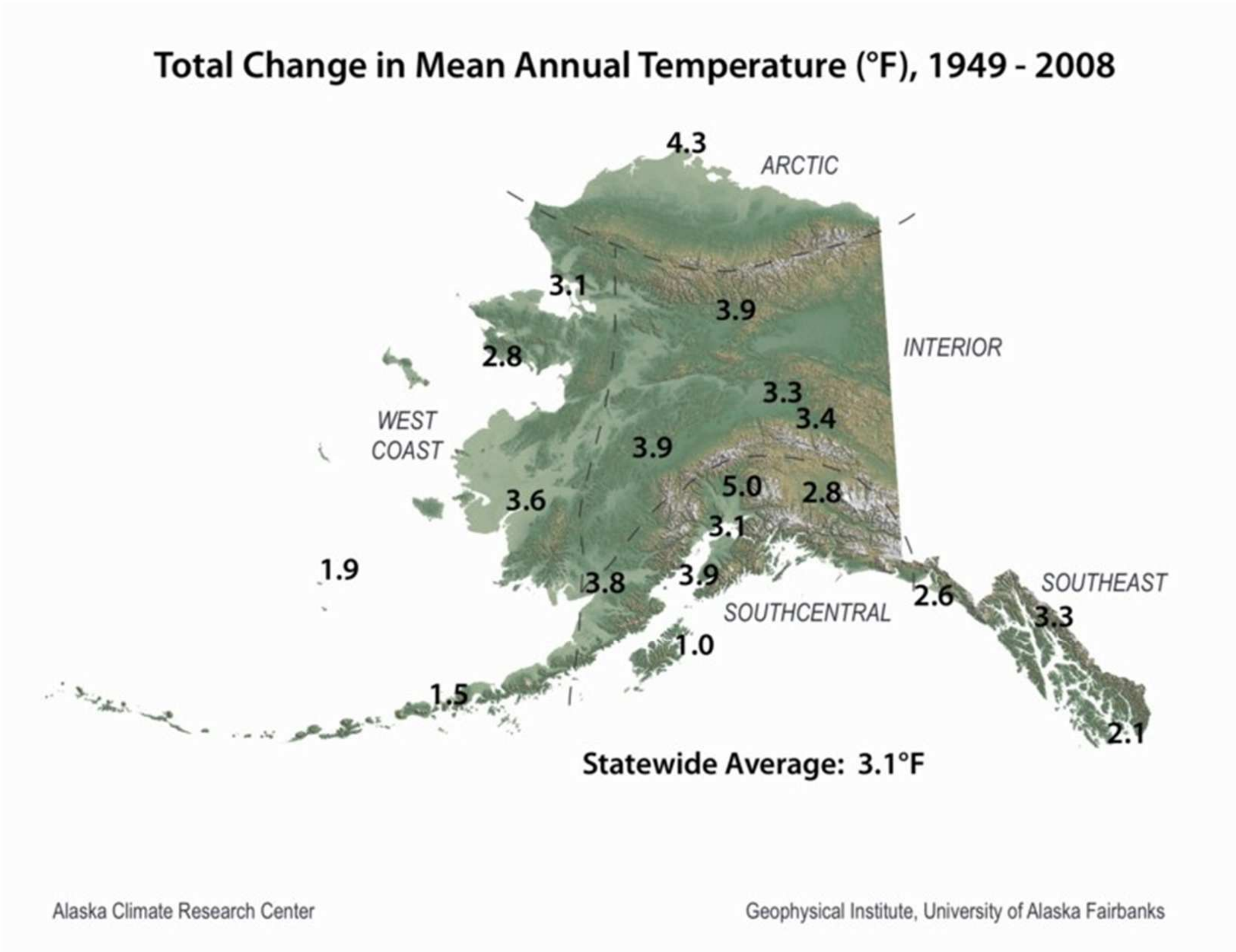
Climate Change

Observed Temperature Change in Alaska



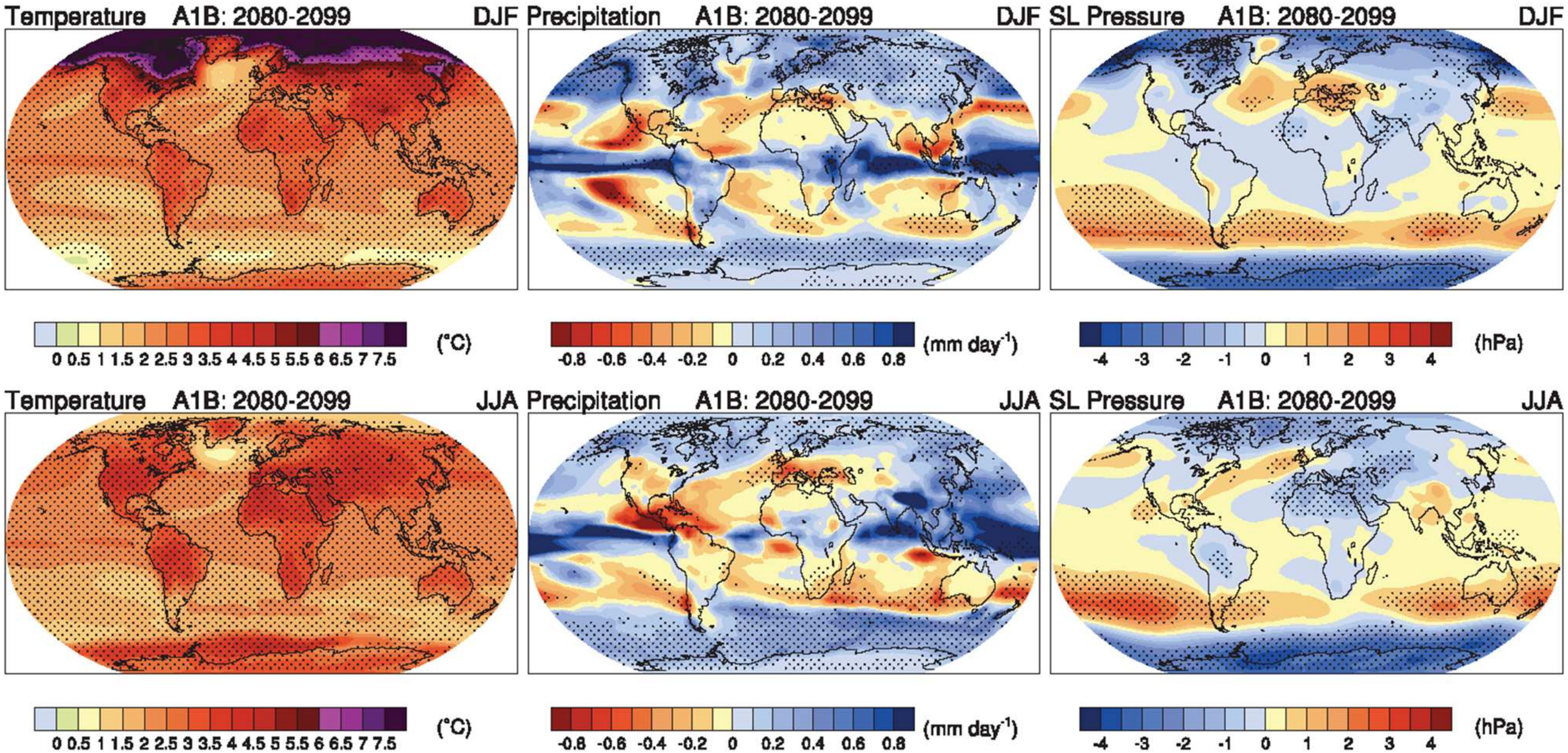
Observed Temperature Change by Season

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

Region	Location	Winter	Spring	Summer	Autumn	Annual
Arctic	Barrow	6.5	4.4	2.8	3.4	4.3
Interior	Bettles	8.5	4.6	1.8	1.1	3.9
	Big Delta	9.2	3.5	1.2	-0.2	3.4
	Fairbanks	7.7	3.8	2.3	-0.4	3.3
	McGrath	7.4	4.8	2.7	0.6	3.9
West Coast	Kotzebue	6.6	1.8	2.5	1.6	3.1
	Nome	4.4	3.6	2.5	0.6	2.8
	Bethel	6.6	5.0	2.3	0.1	3.6
	King Salmon	8.1	4.7	1.8	0.6	3.8
	Cold Bay	1.5	1.8	1.8	0.9	1.5
	St Paul	1.0	2.4	2.8	1.3	1.9
Southcentral	Anchorage	6.8	3.6	1.6	1.4	3.1
	Talkeetna	8.9	5.4	3.1	2.4	5.0
	Gulkana	8.1	2.4	0.9	0	2.8
	Homer	6.3	4.0	3.4	1.7	3.9
	Kodiak	0.9	2.3	1.2	-0.4	1.0
Southeast	Yakutat	4.9	3.1	1.8	0.3	2.6
	Juneau	6.6	3.1	2.1	1.4	3.3
	Annette	3.9	2.5	1.7	0.2	2.1
	Average	6.0	3.5	2.1	0.9	3.1

Alaska Climate Research Center   Geophysical Institute, University of Alaska Fairbanks

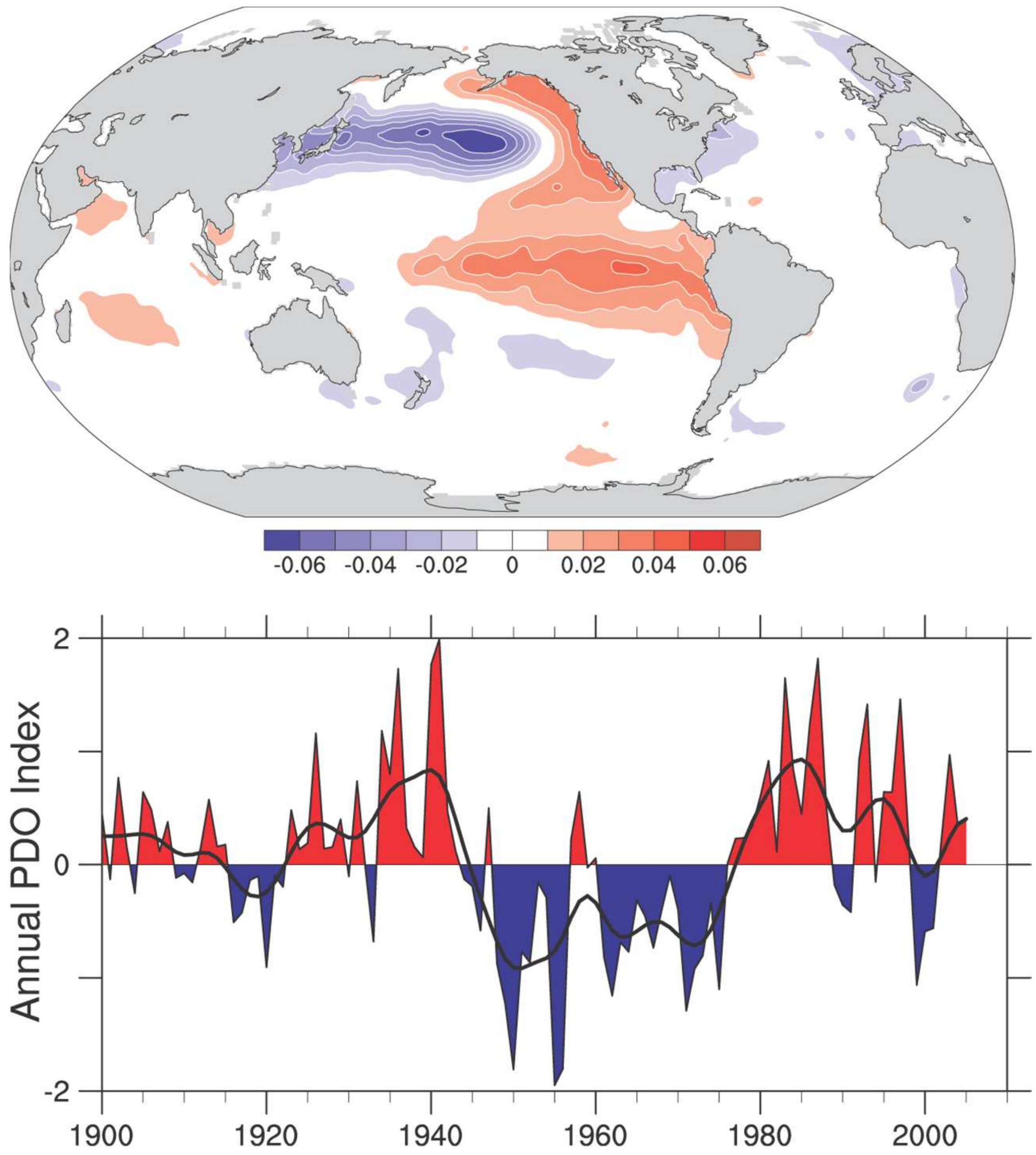
Projected temperature, precipitation, and pressure changes



IPCC AR4, 2007

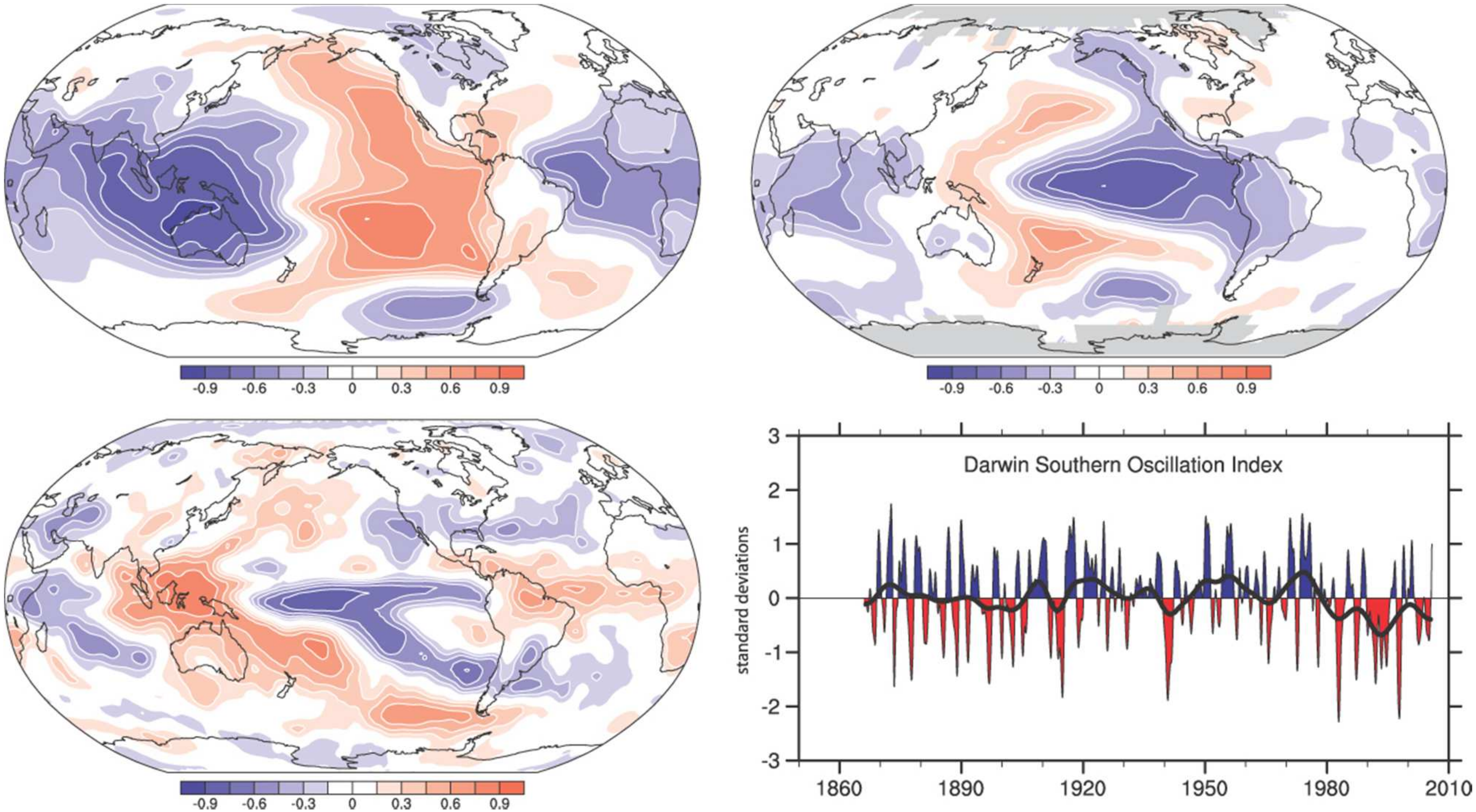
Climate Variability

Observed Climate Variability: PDO



IPCC AR4, 2007

Observed Climate Variability: ENSO



IPCC AR4, 2007

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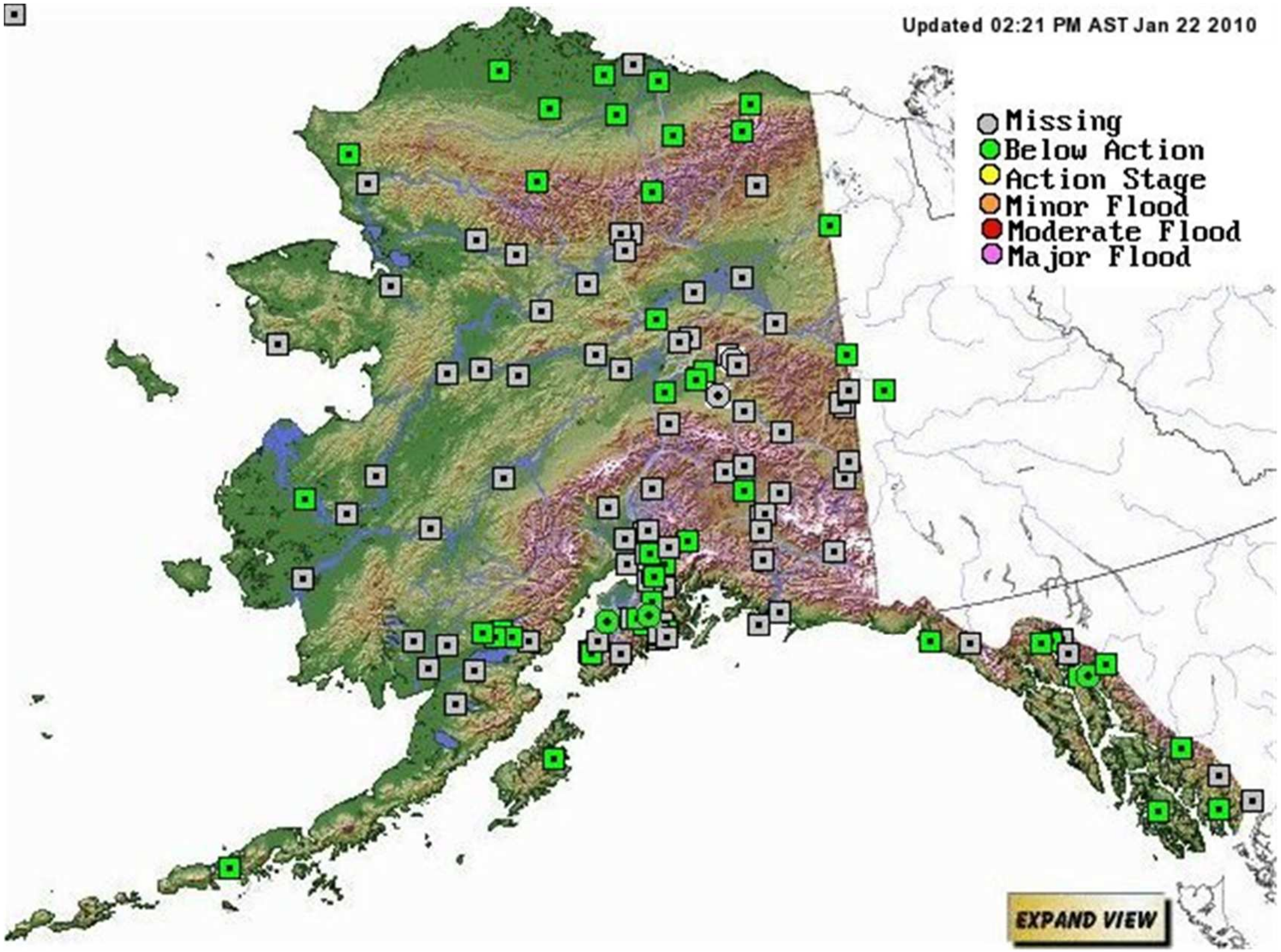
NWS RFC Alaska-Pacific



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Climate Change

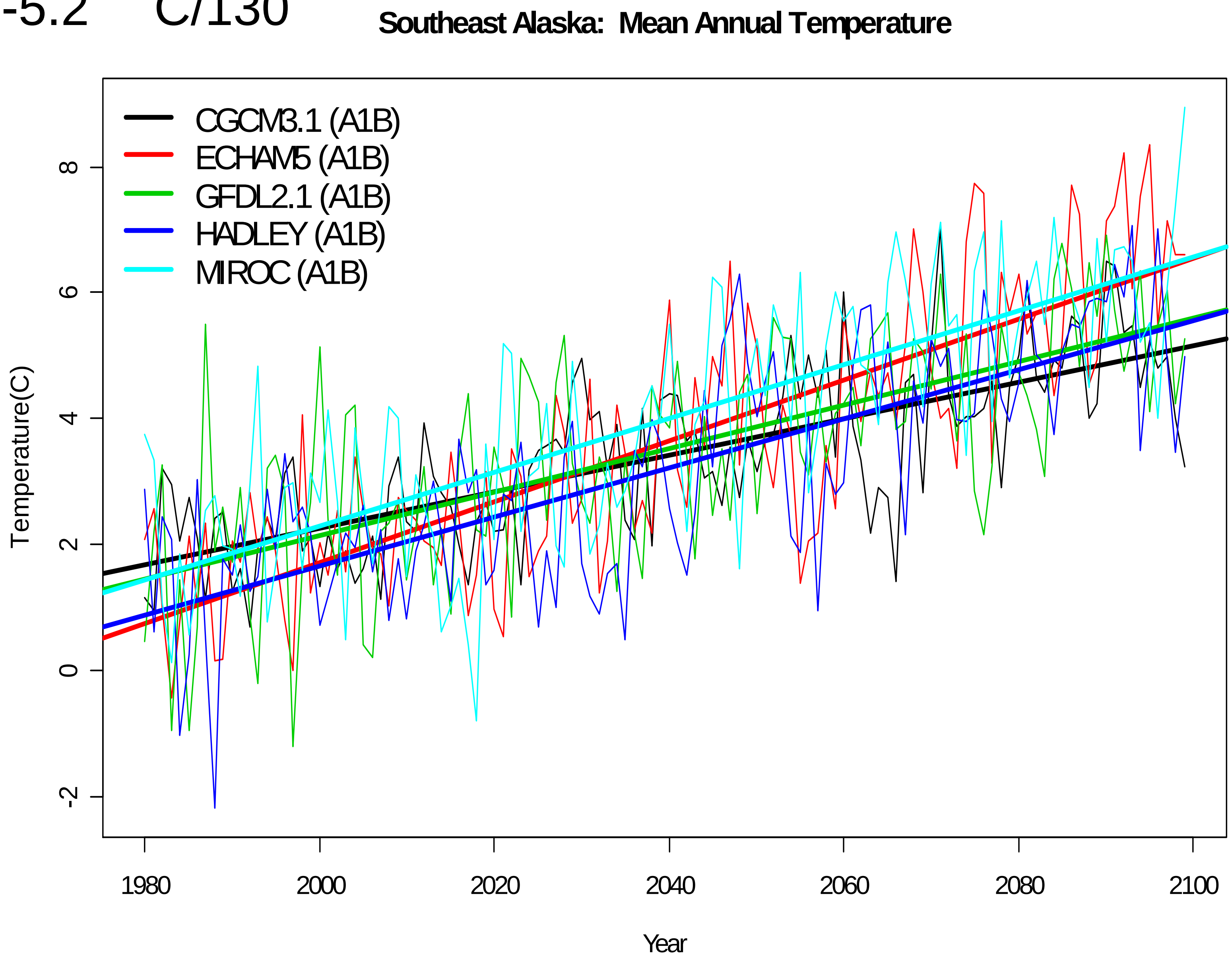
100-year and longer downscaled projections of temperature and precipitation for AK under various scenarios of Greenhouse Gas emissions

Projections of likely changes in soil temperatures, permafrost distributions and impact on groundwater storage

SNAP
Scenarios Network for Alaska Planning

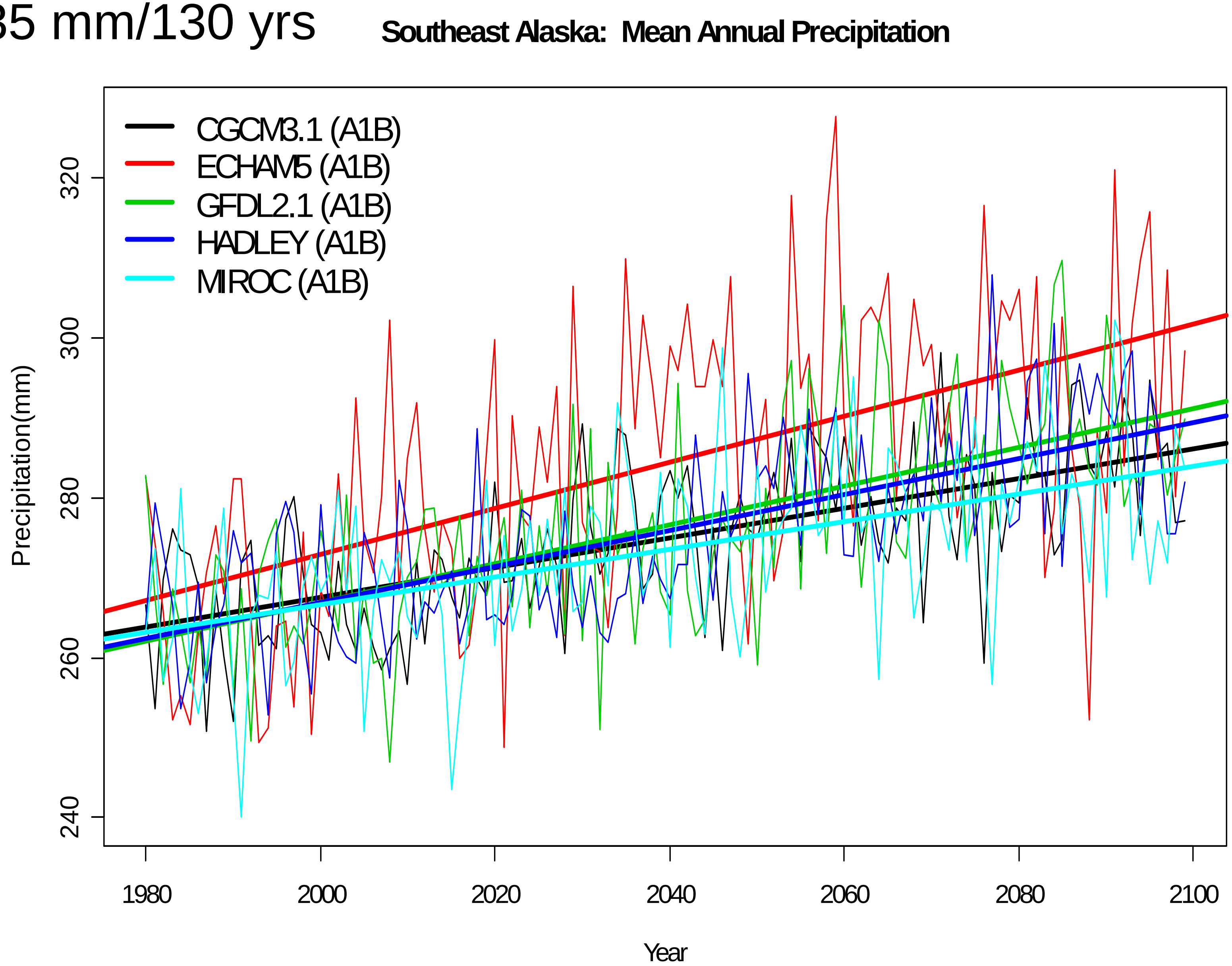
Temp Projections from SNAP for Southeast, AK

3.5-5.2 ° C/130 yrs



Precip Projections from SNAP for Southeast, AK

23-35 mm/130 yrs



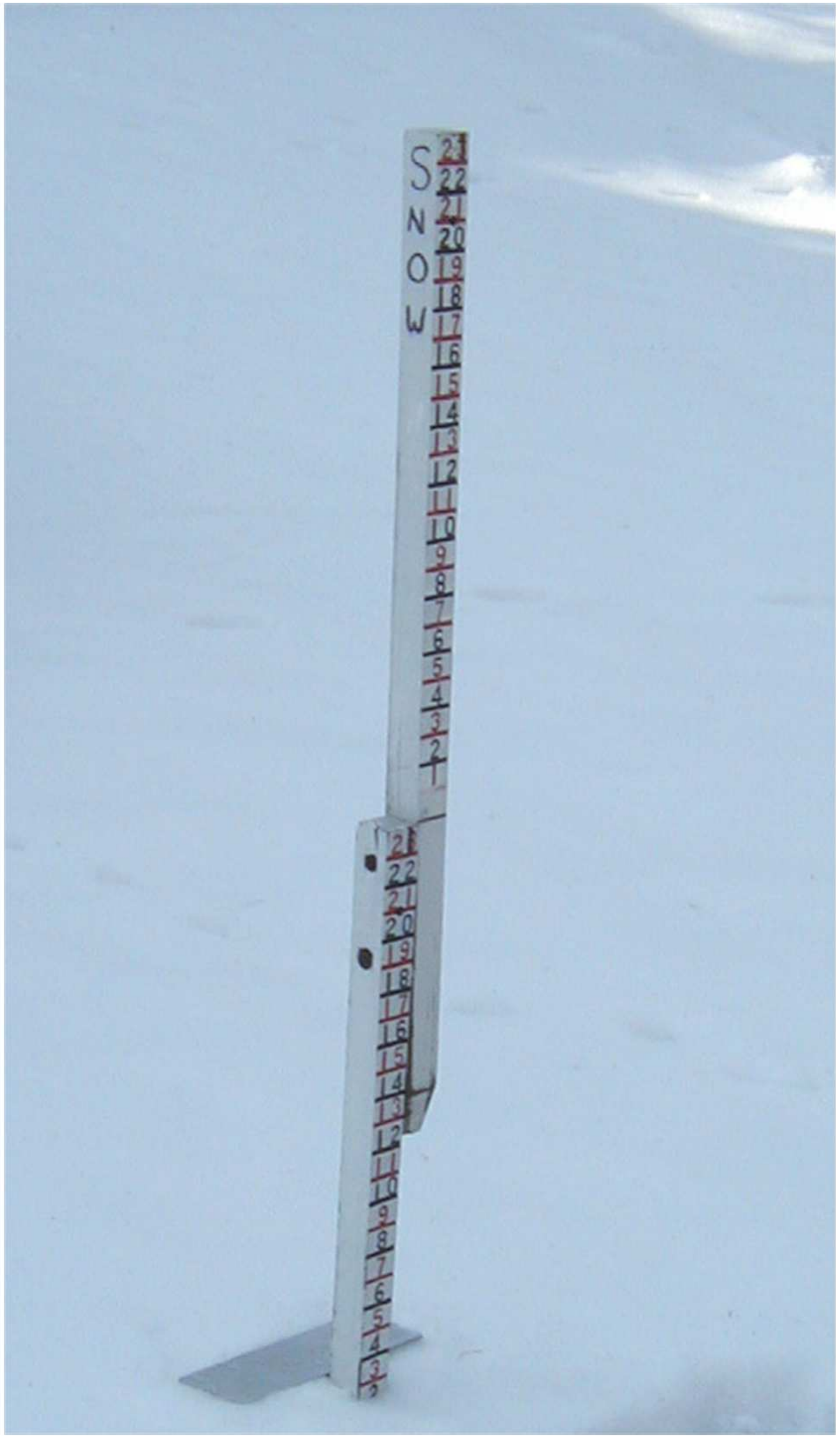
Other things to consider…

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

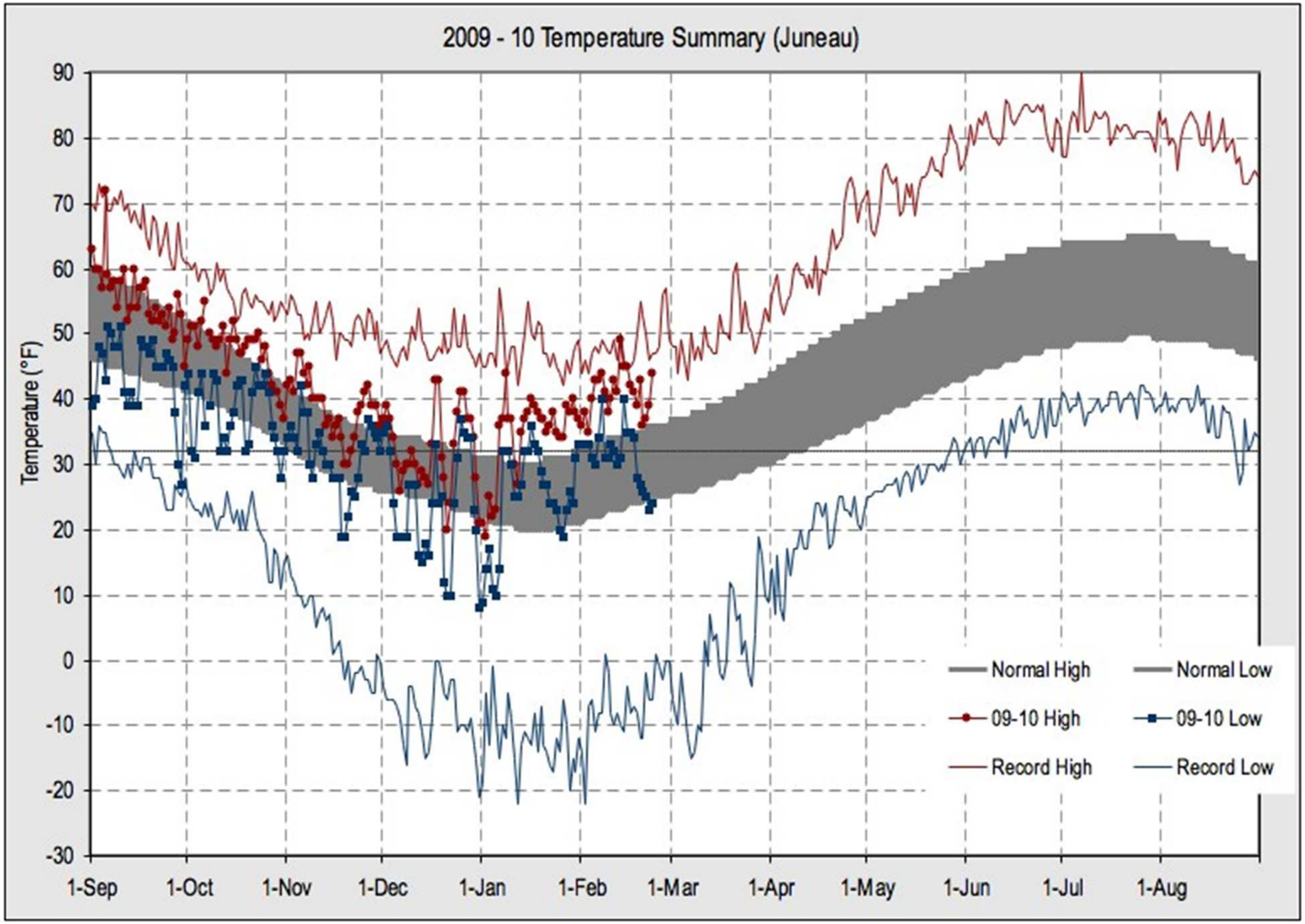
Bottom Line

- 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

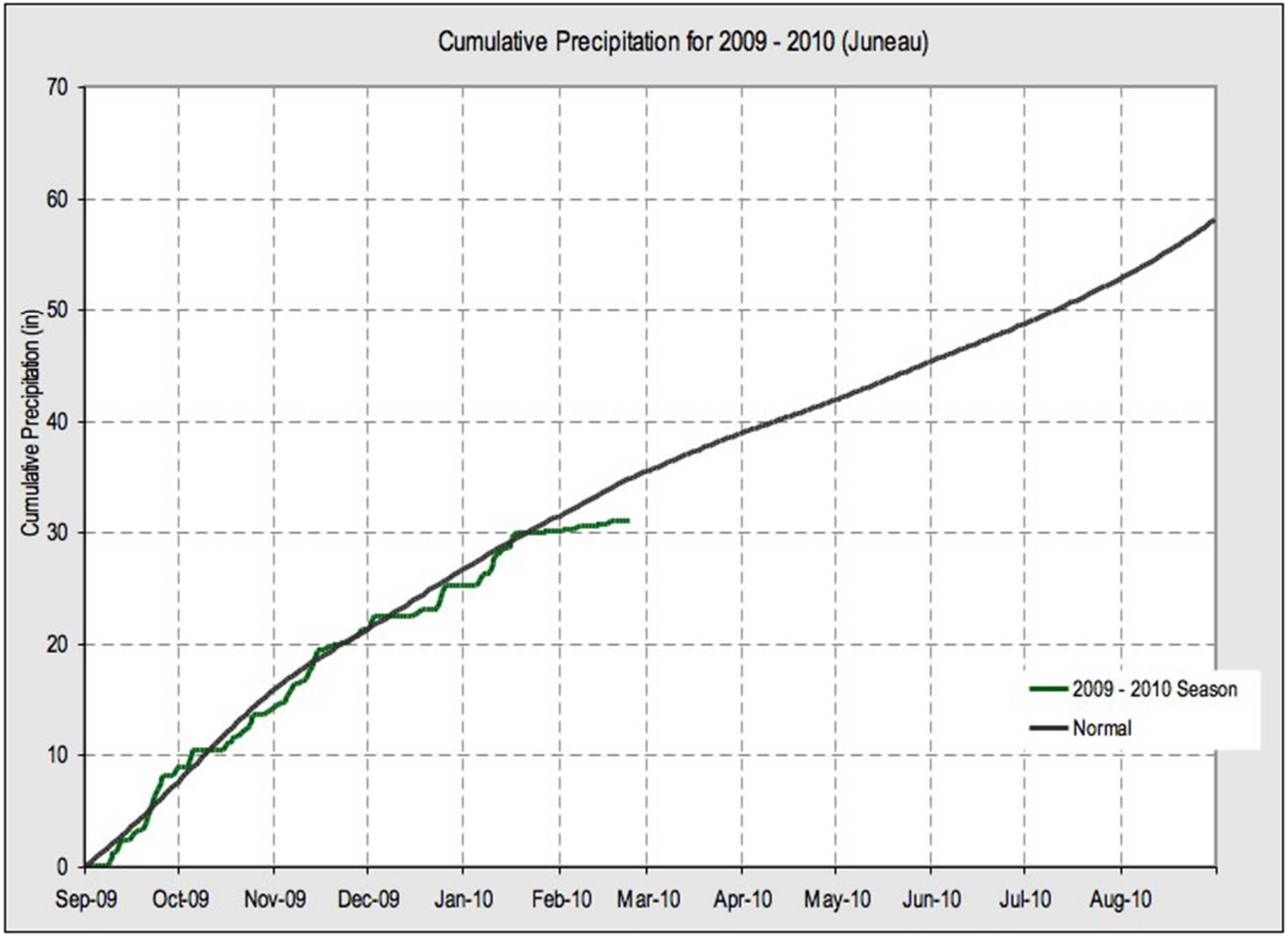
Bottom Line: Recommendations

- 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

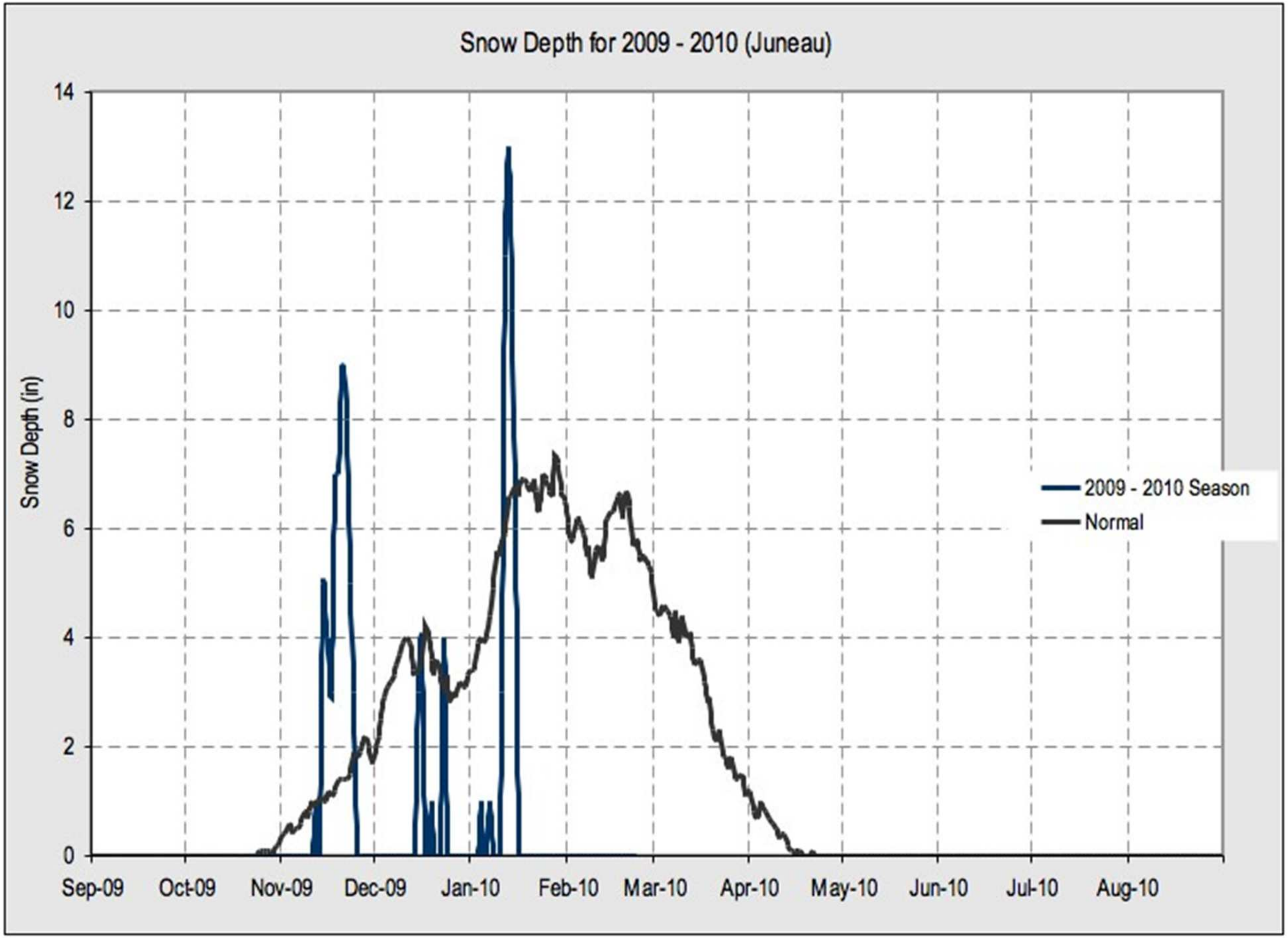
Juneau Climate Anomalies

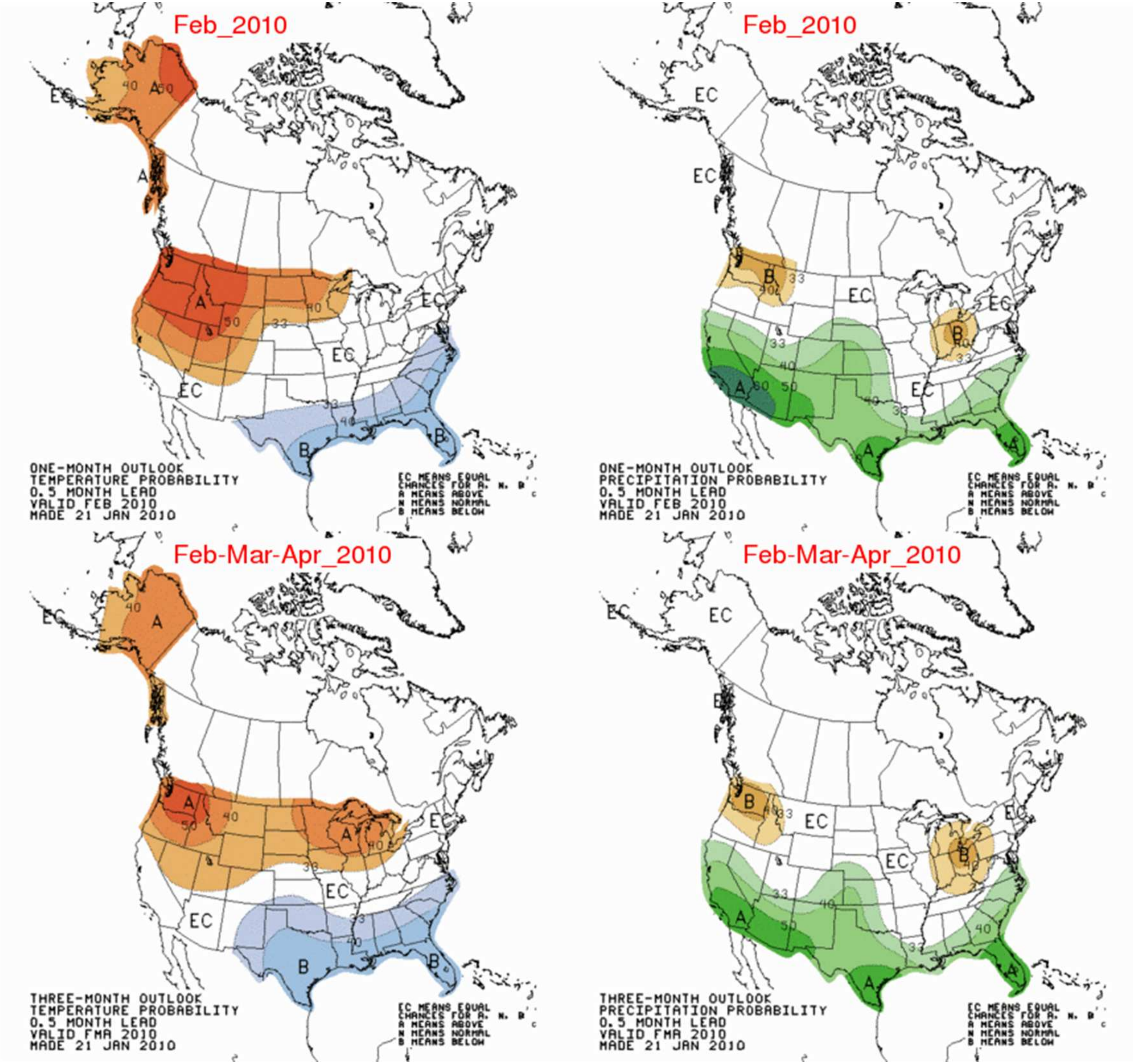


Juneau Climate Anomalies



Juneau Climate Anomalies




Feb_2010
ONE-MONTH OUTLOOK
TEMPERATURE PROBABILITY
0.5 MONTH LEAD
VALID FEB 2010
MADE 21 JAN 2010
EC MEANS EQUAL
CHANCES FOR A, N, B
A MEANS ABOVE
N MEANS NORMAL
B MEANS BELOW
Feb_2010
ONE-MONTH OUTLOOK
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A MEANS ABOVE
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B MEANS BELOW
Feb-Mar-Apr_2010
THREE-MONTH OUTLOOK
TEMPERATURE PROBABILITY
0.5 MONTH LEAD
VALID FMA 2010
MADE 21 JAN 2010
EC MEANS EQUAL
CHANCES FOR A, N, B
A MEANS ABOVE
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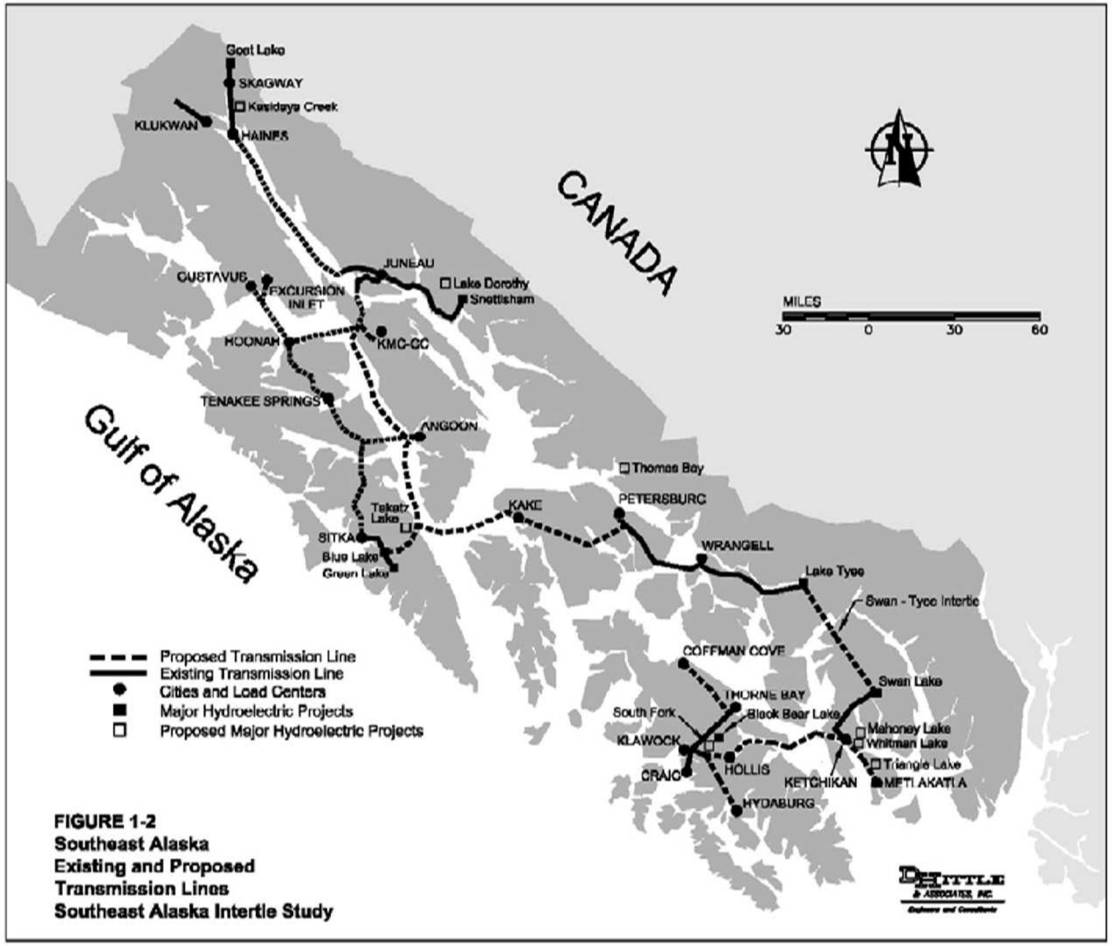
SE Grid – Existing and Proposed



The FOUR DAM POOL Power Agency