MEMORANDUM

TO: Power Committee
FROM: Massoud Jourabchi, Manager Economic Analysis
SUBJECT: Background on Climate Change Models

BACKGROUND:

Presenter: Dr. David Rupp (Oregon State University)

Summary: In this presentation Dr. Rupp will provide a background on what are Global General Circulation Models (GCM). He will discuss genesis of these models, as well as their projections for regional temperature and precipitation over the next few decades. Although all GCMs project increase in temperature and changes in timing of precipitation, degree of change varies across models. The decadal projections for daily minimum and maximum temperatures as well as change in precipitation across the Northwest will used to evaluate impact on loads and hydro generation. This is a high-level summary of a more extended presentation Dr. Rupp has made at Council’s recent workshop on impact of climate change on resource planning.

Relevance: Climate change is anticipated to have both direct (temperature and precipitation) and indirect impacts on the regional use and generation of electricity in the next 20 years.

Global Climate Models
A Very Simple Global Climate Model
Incoming sunlight (shortwave [SW] radiation)
Absorbed Solar Radiation

\[ \text{Absorbed Solar Radiation} = (1 - \text{Albedo}) \times \text{Incoming Solar Radiation} \]

Outgoing heat (longwave [LW] or IR radiation)
“Blackbody” emission

[Stephan-Boltzmann’s Law]:

Outgoing IR Radiation = 

\[ 5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4} \times (\text{Temperature [in K]})^4 \]

The greater the temperature, the greater the emitted radiation

Karen Shell
Absorbed solar [SW] radiation = outgoing IR [LW] radiation

\[(1 - \text{Albedo}) \times \text{Incoming Solar Radiation} = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (\text{Temperature [in K]})^4\]

\[
\text{Albedo} = 0.3 \\
\text{Incoming Solar Radiation} = 340 \text{ Wm}^{-2}
\]

⇒ Earth’s temperature is 255 K (-18 degrees C, -0.4 degrees F)
Earth’s temperature is 288 K (15 degrees C, 59 degrees F)
This is the Greenhouse Effect

Emitting more greenhouse gases creates an energy imbalance. This imbalance is called radiative forcing.
The hard part...

Quantifying the climate **feedbacks** to changing greenhouse gas concentrations
Global climate model building blocks
Why is there a wide range in climate projections?

Radiative forcing + Climate sensitivity + Natural variability
Emissions Scenarios

4 Representative Concentration Pathways (RCPs)

**RCP8.5:** reaches ~8.5 w/m² by 2100

**RCP6.0:** stabilizes at ~6.0 w/m² by 2150

**RCP4.5:** stabilizes at ~4.5 w/m² by 2100

**RCP2.6:** peaks at ~3.0 w/m² in ~2040, declines to ~2.6 w/m² by 2100

Meinshausen et al. 2011
GCMs show different climate sensitivities

“Transient climate response is likely in the range 1°C to 2.5°C”
– IPCC AR5

Transient climate response = temperature increase at time of doubling CO₂ while increasing CO₂ by 1% per year
The butterfly effect: initial conditions and internal variability
Initial conditions and internal variability

Model: CanESM2
Domain: US PNW

Run #1

Modeled changes relative to 1950-1999 baseline.

RCP8.5
Initial conditions and internal variability

Model: CanESM2
Domain: US PNW

Run #2

Modeled changes relative to 1950-1999 baseline.

RCP8.5
Initial conditions and internal variability

Model: CanESM2
Domain: US PNW

Run #3

Modeled changes relative to 1950-1999 baseline.

RCP8.5
Run #4

Model: CanESM2

Initial conditions and internal variability

Winter (DJF)

Domain: US PNW

Modeled changes relative to 1950-1999 baseline.

RCP8.5
Initial conditions and internal variability

Model: CanESM2  
Domain: US PNW

Winter (DJF)

Run #5

Modeled changes relative to 1950-1999 baseline.  
RCP8.5
Earth System Models

Developed to account for all the major processes that affect the climate

Increasing in complexity

Despite improvements, slow to converge towards a common *climate sensitivity*
An overview of the Representative Concentration Pathways
The four Representative Concentration Pathways (RCPs):

8.5, 6.0, 4.5, & 2.6
The four Representative Concentration Pathways (RCPs):

8.5, 6.0, 4.5, & 2.6

What do these numbers mean?
“8.5” = 8.5 Watts per square meter
RCP 8.5
A heterogeneous world
High population growth

World population
2019: 7.7 billion
2100: >12 billion
High population growth

Slow economic growth
High population growth

Slow economic growth

Low rates of energy intensity improvements
High population growth

Slow economic growth

Low rates of energy intensity improvements

High rates of energy consumption focused on low grade, regionally available resources
RCP 2.6
Limiting global warming to 2°C
Is it technologically feasible to limit warming to 2 degrees C?
Is it technologically feasible to limit warming to 2 degrees C?

Assumptions: medium economic growth, moderate rates of energy intensity improvements, geopolitical landscape not characterized by conflict and lack of international agreements
RCP2.6
Primary mitigation measure: carbon capture and storage (CCS)

Van Vuuren et al., 2011
RCP 4.5
A cost-minimizing pathway to stabilization
Common global pricing on emissions

All nations participate

All sectors included

All available technology options used to minimize cost
RCP4.5

Global electricity production by source

Thompson et al., 2011
RCPs: Greenhouse gas concentrations

Van Vuuren et al., 2011
Climate model/scenario selection for the northwest US
Climate model/scenario selection: a 2-part process

1. Historical performance
2. Future projections
GCM Performance Quilt

18 Metrics
31 GCMs

Relative error

Highest
Lowest

Less error
GCM
More error
2030s climate projections for the Columbia River Basin

Increased precipitation = more intense precipitation, not more frequent precipitation

**Above The Dalles**
2030s precipitation projections for the Columbia River Basin**

**Above The Dalles**

The RMJOC-II "10"

1. CanESM2  
2. CCSM4  
3. CNRM-CM5  
4. CSIRO-Mk3-6-0  
5. GFDL-EMS2M  
6. HadGEM2-CC  
7. HadGEM2-ES  
8. inmem4  
9. IPSL-CM5A-MR  
10. MIROC5

**Above The Dalles**
Extra slides
Fish habitat is expected to degrade due to increasing peak flows, earlier streamflow timing, reduced summer low flows, and warming summer stream temperatures that could shift preferred habitats, alter the timing of life history stages, and exacerbate current stressors for the Pacific Northwest’s salmon and steelhead (Oncorhynchus spp.) and other aquatic wildlife.

Climate change impacts on fish

Warmer temperatures, shift from snow to rain, and higher rainfall intensities increase risk of:

• Lethal stream temperatures
• Scouring of shallow-buried eggs from heavier winter streamflow
• Downstream migration timing of smolts desynchronized with spring freshet
• Upstream migration in summer/fall delayed by lower summer flow
<table>
<thead>
<tr>
<th>Model</th>
<th>Rupp et al. (2013)</th>
<th>Atmospheric rivers</th>
<th>1-5 year drought</th>
<th>Global precipitation</th>
<th>Temperature, annual</th>
<th>Temperature, winter</th>
<th>Temperature, spring</th>
<th>Temperature, summer</th>
<th>Temperature, fall</th>
<th>Precipitation, annual</th>
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**Performance**
- A: Better
- B: Medium
- C: Poorer

**Relative change in temperature**
- High warming
- Near-mean warming
- Medium-low warming
- Low warming

**Relative change in precipitation**
- High increase
- Medium high increase
- Near-mean increase
- Medium-low increase
- Low increase

**Relative change in precipitation**
- High decrease
- Medium high decrease
- Near-mean decrease
- Medium low decrease
- Low decrease