VECCs

Variable Energy Content Curves

Nancy Stephan
Bonneville Power Administration
RMJOC Climate Change Data Set Workshop
June 9, 2009

What are they?

End of Month contents of a reservoir that is the lowest level to which the reservoir may be drawn in order to produce secondary energy and still refill by the end of July with 95% confidence.

Water Supply Forecasts

Location	Water Supply Forecast Source	Forecast Period(s)
Mica	BC Hydro	Jan-Jul, Apr-Aug, May-Jul
Arrow	BC Hydro	Jan-Jul
Duncan	BC Hydro	Jan-Jul, Apr-Aug, May-Jul
Libby	U.S. Army Corps of Engineers	Jan-Jul, Apr-Aug, May-Jul
Dworshak	U.S. Army Corps of Engineers	Jan-Jul, Apr-Jul, May-Jul
Brownlee	NWRFC/NRCS	Jan-Jul, Apr-Jul
Hungry Horse	Bureau of Reclamation	Jan-Jul, Apr-Aug, May-Jul, May-Sep
Grand Coulee	NWRFC/NRCS	Jan-Jul
Lower Granite	NWRFC/NRCS	Jan-Jul, Apr-Jul
The Dalles	NWRFC/NRCS	Jan-Jul, Apr-Aug

Why are they computed?

- The VECC computation is done to update the 95% confidence lower limits for new forecast information. In this case VECC's are computed after the release of each official Water Supply Forecasts.
- The computed VECC's are then input to the Treaty Storage Regulation (TSR) computation.
- The computed VECC's for the Canadian projects are also passed to Northwest Power Pool (NWPP) to include in the Actual Energy Regulation (AER).

What will need to be developed?

- CC water supply forecasts
- CC forecast errors
- CC runoff distributions
- Mica, Arrow, Duncan, Dworshak, Libby, Grand Coulee, Hungry Horse

Water Supply Forecasts

Nancy Stephan
Bonneville Power Administration
RMJOC Climate Change Data Set Workshop
June 9, 2009

Current "Official Forecasts"

- Methodologies currently in use for "Official Forecasts" are statistical:
  - Multiple Linear Regression
  - Principle Component Analysis
- Monthly, Seasonal Volume, Residual Volume
- Early Season forecasts (Nov 1, Dec 1)
- Associated forecast errors (cross-validation standard error)

Predictors used to make Water Supply Forecasts

- Fall/Winter precipitation
- Snowpack (SWE)
- Spring precipitation
- Antecedent runoff
- Temperature (used in BCH forecast)
- Climate Indices: Southern Oscillation Index
  Multivariate ENSO Index

Water Supply Forecasts

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The Dalles	NWRFC/NRCS	Jan-Jul, Apr-Aug

Water Supply Forecasts Used to Implement BiOp Actions

Table 3. Water Supply Forecasts Used to Implement BiOp Actions

Forecast Point	Forecast period	Forecast	BiOp actions determined
Hungry Horse	April – August	January, February, and March Final provided by Reclamation	Columbia Falls and Hungry Horse minimum flows
The Dalles	April – August	April Final July Final Provided by NWRFC	Spring flow objective at McNary Dam Summer draft elevation for Grand Coulee (August 31 elevation of 1280 feet or 1278 feet) Juvenile Fish Transport operations at McNary Libby Summer Draft Limit Hungry Horse Summer Draft Limit
Lower Granite	April – July	April Final Provided by NWRFC	Spring flow objective at Lower Granite Juvenile Fish Transport operations at Lower Snake Projects
Lower Granite	April – July	June Final Provided by NWRFC	Summer flow objective at Lower Granite
The Dalles	April – August	July Final Provided by NWRFC	Grand Coulee summer draft limit
Libby	April – August	May Final Provided by CORPS	Volume of water to provide for sturgeon and minimum bull trout flows to begin generally May 15
Libby	April – August	April, May, June Final Libby Forecast provided by Corps,	VARQ Refill Flows
Hungry Horse	May – September	April, May, June Final Forecast provided by Reclamation	VARQ Refill Flows

What are the volumes used for?

- To-date – July: Calculate Treaty projects power draft rights (VECC)
- April – Aug (Jul): Flood Control
  Determine Refill Curves
  Bi-Op, Fish operations
- May – Jul (Sep): Refill Curve for HGH

Forecast Errors

The Dalles:

- January – July = 104 maf
- Jan1 – SE 16.6 maf (95% confidence 27.3 maf)
- Feb1 – SE 12.4 maf (95% confidence 20.1 maf)
- Mar1 – SE 9.4 maf (95% confidence 15.5 maf)
- Apr1 – SE 7.1 maf (95% confidence 11.7 maf)

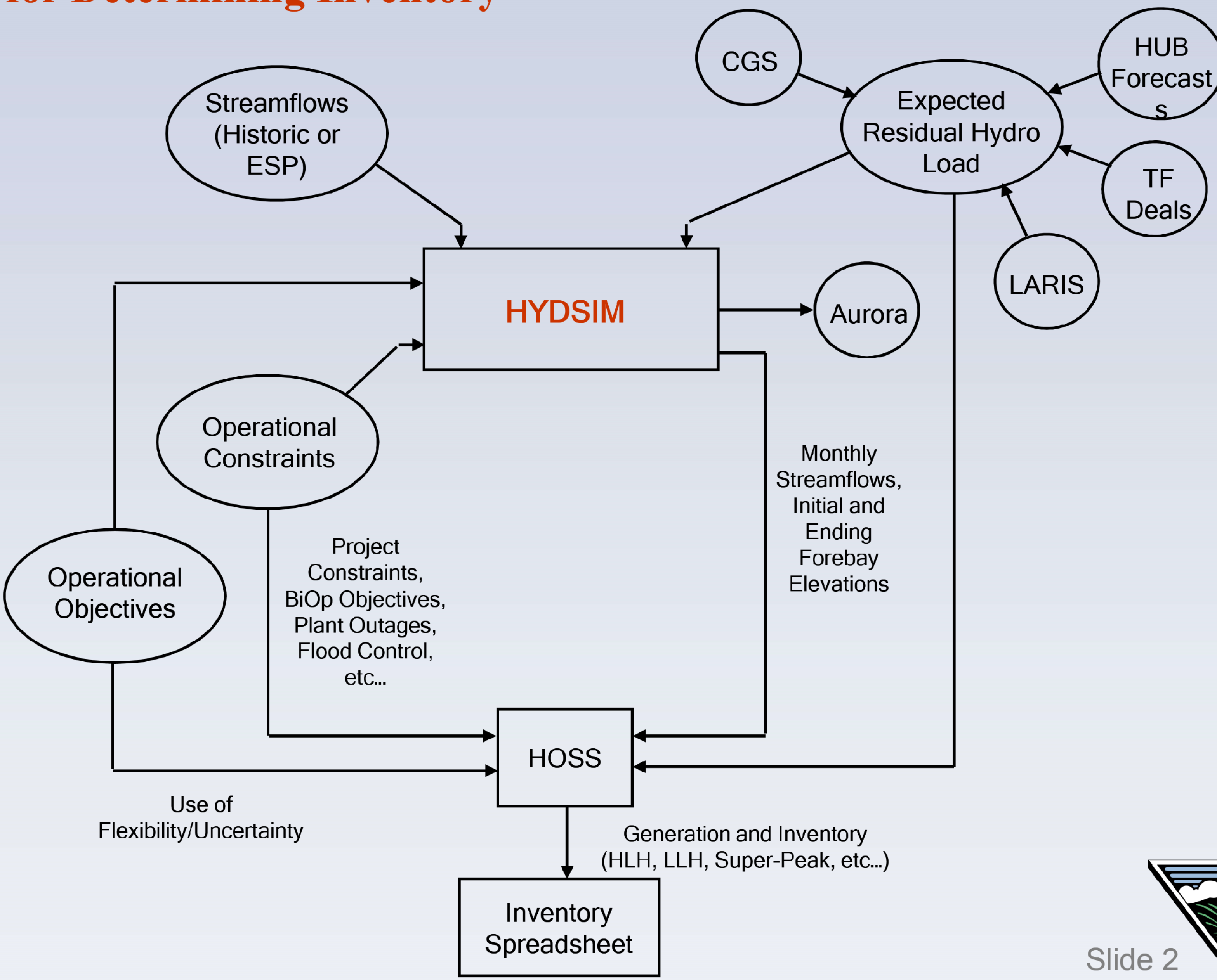
Bonneville Power Administration Hydsim Model

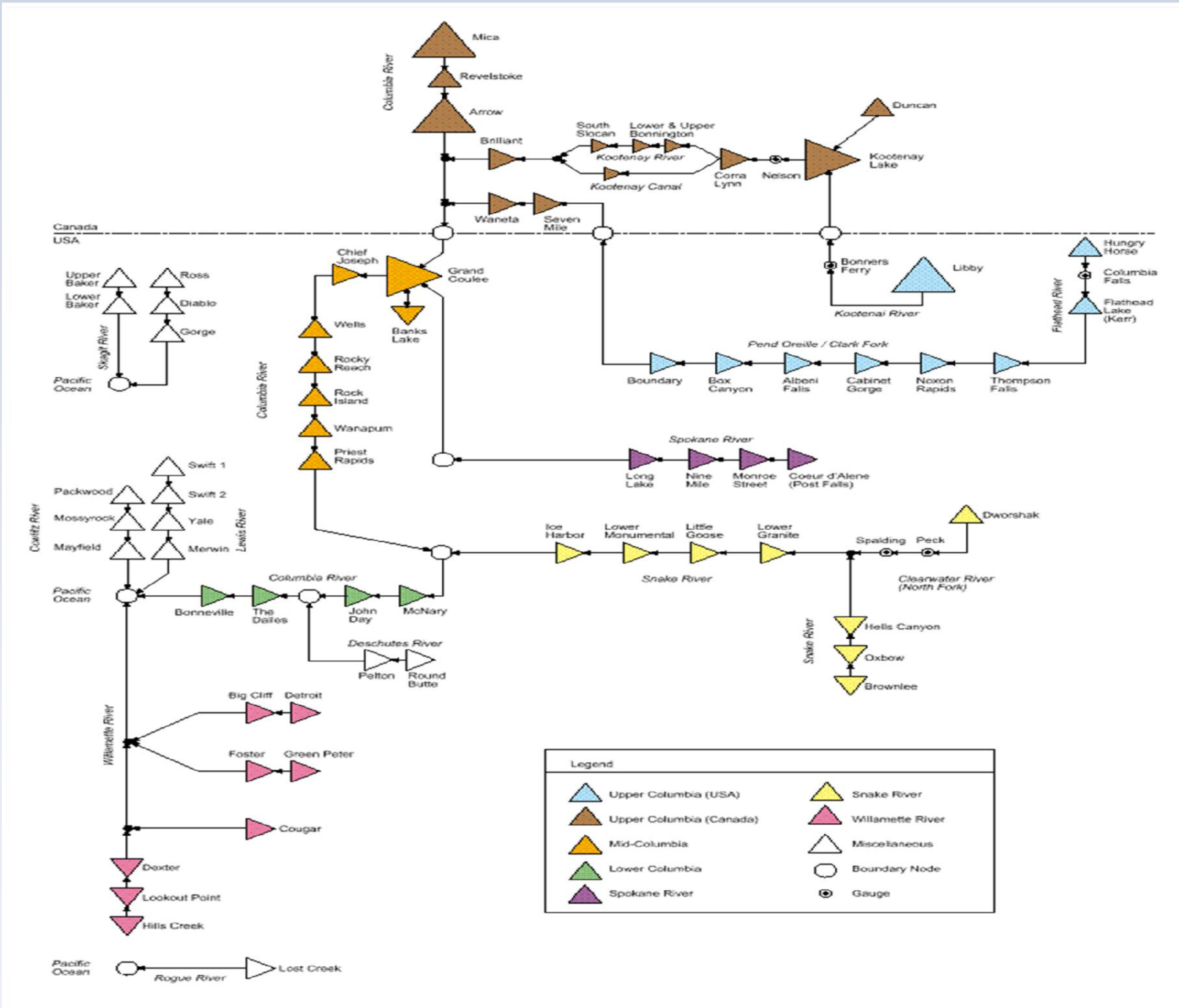
Nancy Stephan

RMJOC Climate Change Data Set Workshop

June 9th, 2009

Process for Determining Inventory




Mica
Revelstoke
Arrow
Columbia River
Brilliant
South Slocan
Lower & Upper Bonnington
Kootenay River
Kootenay Canal
Corra Lynn
Nelson
Duncan
Kootenay Lake
Waneta
Seven Mile
Canada
USA
Bonners Ferry
Libby
Kootenai River
Hungry Horse
Columbia Falls
Flathead Lake (Kerr)
Flathead River
Pend Oreille / Clark Fork
Boundary
Box Canyon
Albeni Falls
Cabinet Gorge
Noxon Rapids
Thompson Falls
Chief Joseph
Grand Coulee
Banks Lake
Wells
Rocky Reach
Rock Island
Wanapum
Priest Rapids
Columbia River
Upper Baker
Lower Baker
Ross
Diablo
Gorge
Skagit River
Pacific Ocean
Spokane River
Long Lake
Nine Mile
Monroe Street
Coeur d'Alene (Post Falls)
Swift 1
Swift 2
Yale
Merwin
Lewis River
Packwood
Mossyrock
Mayfield
Cowlitz River
Pacific Ocean
Ice Harbor
Lower Monumental
Little Goose
Lower Granite
Snake River
Spalding
Peck
Dworshak
Clearwater River (North Fork)
Columbia River
Bonneville
The Dalles
John Day
McNary
Deschutes River
Pelton
Round Butte
Hells Canyon
Oxbow
Brownlee
Snake River
Willamette River
Big Cliff
Detroit
Foster
Green Peter
Cougar
Dexter
Lookout Point
Hills Creek
Pacific Ocean
Rogue River
Lost Creek
Legend
Upper Columbia (USA)
Upper Columbia (Canada)
Mid-Columbia
Lower Columbia
Spokane River
Snake River
Willamette River
Miscellaneous
Boundary Node
Gauge

Key Inputs

- **Loads**
- **Streamflows**
  - Historical (2000 Level Modified streamflows 1929-1998)
  - ESP (1949-1992, generated via NWSRFS)
- **Operational Constraints**
  - Hard Project Constraints (flow limits, elevation limits, etc.)
  - Project Outages
  - Non-Power Constraints (Flood Control, fish VECCs, Banks Lake adjustment, Fish Operations, BiOp, TSR and Supplemental Operating Agreements, etc.)

Key Inputs (cont.)

- **Operational Objectives**
  - Uncertain objectives (Chum Protection, summer spill on Lower Snake projects, etc.)
  - Flexible Objectives (fall operation of Grand Coulee, supplemental operating agreements with Canada, etc.)
  - Marketing and Load obligations

Hydsim

- Month-average results, except for April and August which are split into two periods
- Uses a set of user defined priorities to resolve conflicting constraints
- Can use either ESP or historical streamflows
- Can run in two modes
  - Refill: initial elevations are independent of previous water year's ending elevation)
  - Continuous: initial elevation are set equal to the previous water year's ending elevation
- Multi-step process:
  - TSR step sets the Canadian base operation
  - OPER step regulates remainder of the system and adjusts Canadian operation as necessary
- Requires a set of pre-/post-processing tools for easily preparing the constraints and for simplifying analysis of the results
- Regional generation fed to Aurora for price analysis

RMJOC Climate and Hydrology Dataset for use in Agencies' Longer-Term Planning Studies

Nancy Stephan
Bonneville Power Administration
PMC Meeting
May 20, 2010
Portland Oregon

RMJOC* Motive and Need

- **Motive**
  - consistent incorporation of climate projection information into Agencies' longer-term planning studies
- **Need**
  - adopt common dataset (climate and hydrology)
  - establish consensus methods for data use
  - efficiently use limited resources through coordinated development of data and methods

Key Scoping Decisions

1. Use CIG's forthcoming data on regional climate and hydrology (CIG's "HB2860" regional project)
2. Use two methodologies from CIG
   - Step-change climate information (Hybrid)
   - Time-developing climate information (Transient)

2. Use only a subset of both data sets

3. Conduct demonstration analysis using both types to draw impressions on which types are more appropriate for various types of Agencies' longer-term planning

CIG Study Partnerships

Funding Partners:
WA Department of Ecology (via HB 2860)
Bonneville Power Administration
Northwest Power and Conservation Council
Oregon Water Resources Department
BC Ministry of the Environment

Collaborative Partners:
Montana Department of Natural Resources
Idaho Department of Water Resources
USBR, Boise Regional Office
USACE, Seattle and Portland Districts

Data from CIG Effort

- Develop historic driving meteorological data at 1/16th degree (7 kilometer) from 1915- 2005
- Produce downscaled 1/16th degree driving data sets associated with each of 10 GCM scenarios for “2020” “2050” “2080” time periods
- Run the 1/16th degree VIC model for each of 10 GCM scenarios for the three time periods, and produce streamflow scenarios for over 200 inflow locations
- Adjust natural flow scenarios to estimate monthly Modified Flows for all Hydsim sites

Project Status

TASK	STATUS
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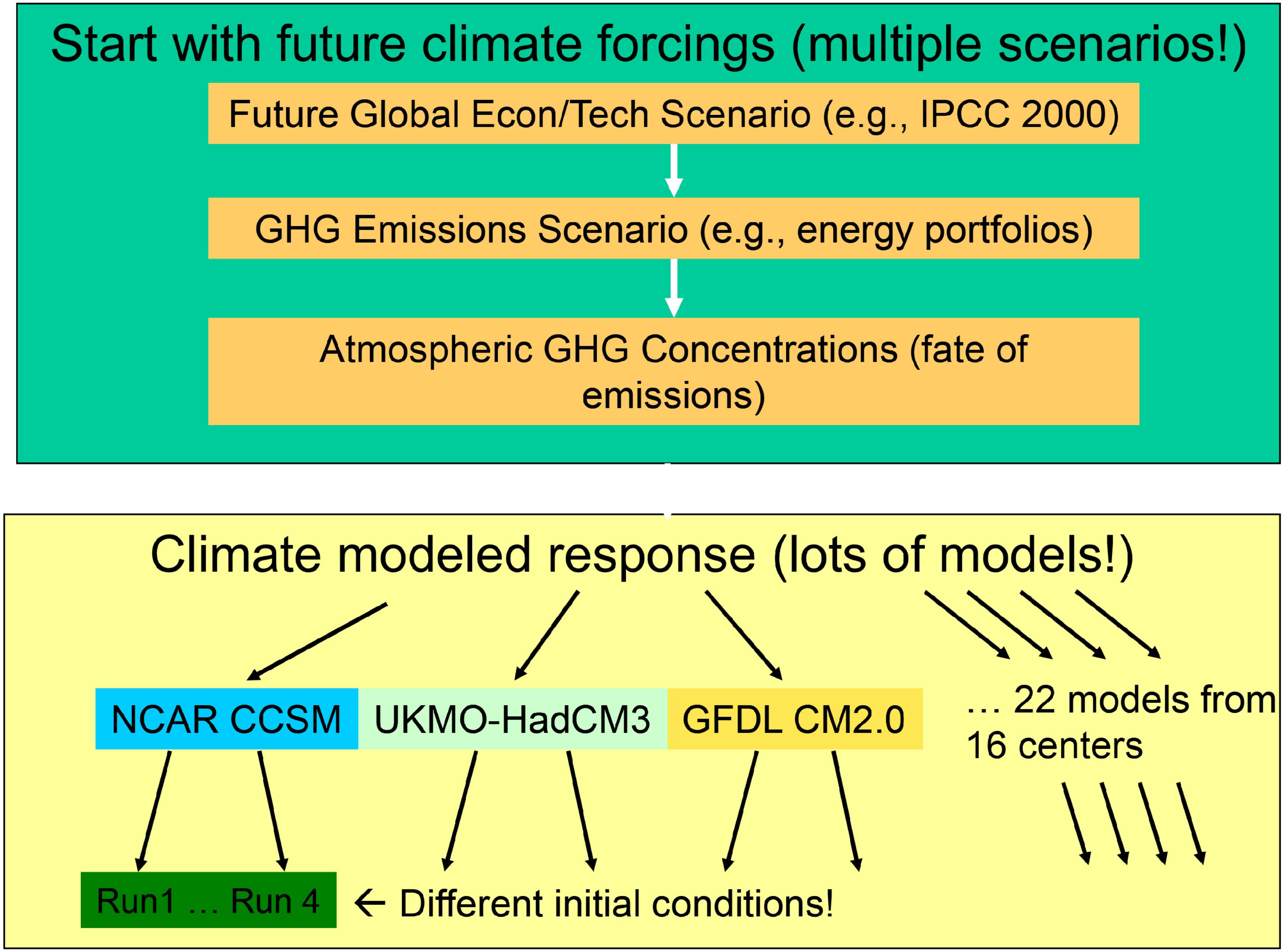
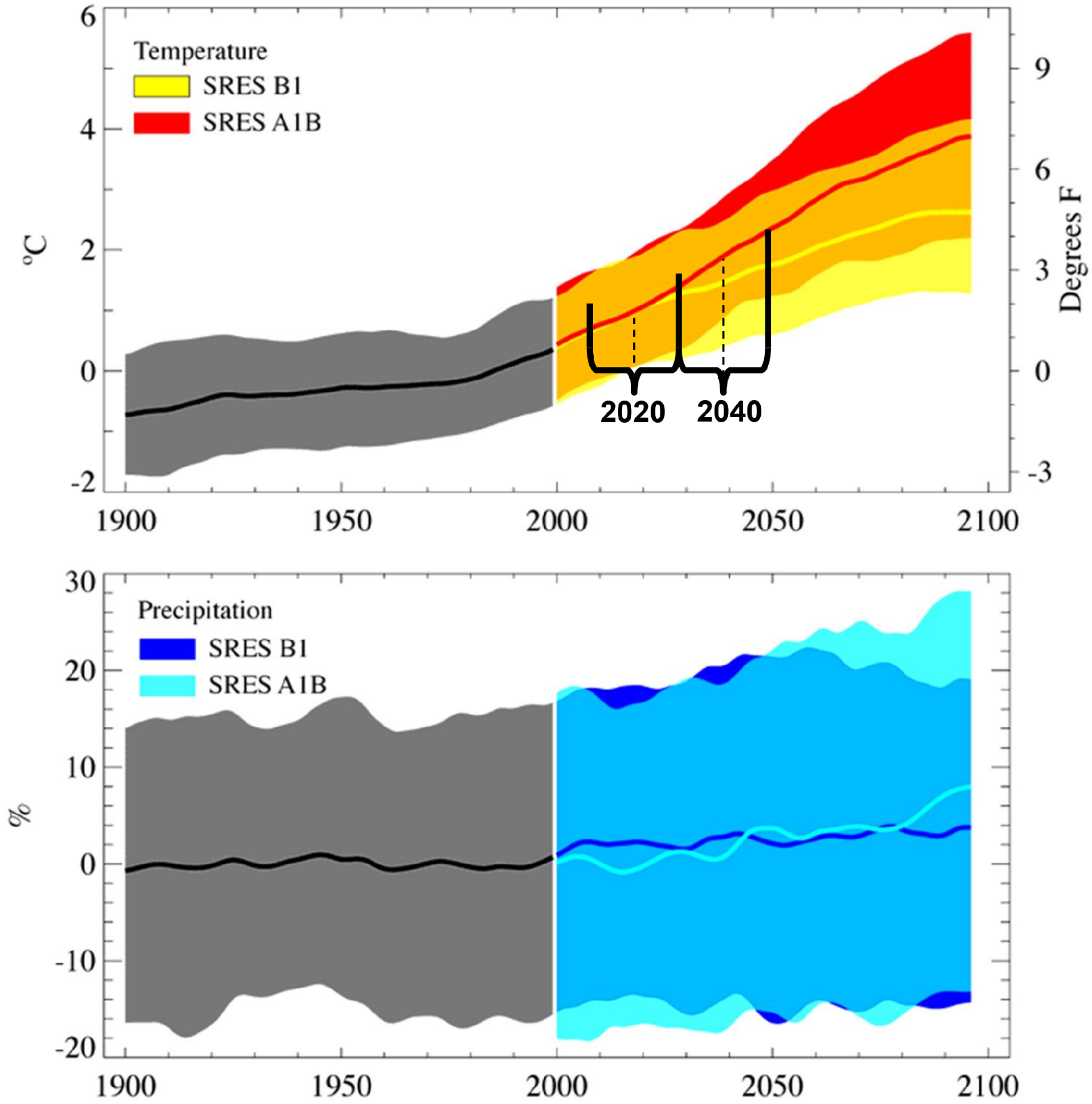
More than just a few choices



Courtesy: Barsugli



Future Climate in the Northwest: Philip W. Mote and Eric P. Salathé Jr.

What subsets are appropriate for planning purposes?
Which data type is best for each planning study?

"*Hybrid-Delta*" or step-change data ("climate change")

20 Climate Projections

10 Global Climate Models X **A1b and B1 emission scenarios** X **sampled changes from 1971-2000 to either… 2010-2039 2040-2069**

= 40"climate change" hydrologic scenarios, each 91 years in duration, having variability as observed from 1915-2005

"*Transient*" or time-developing

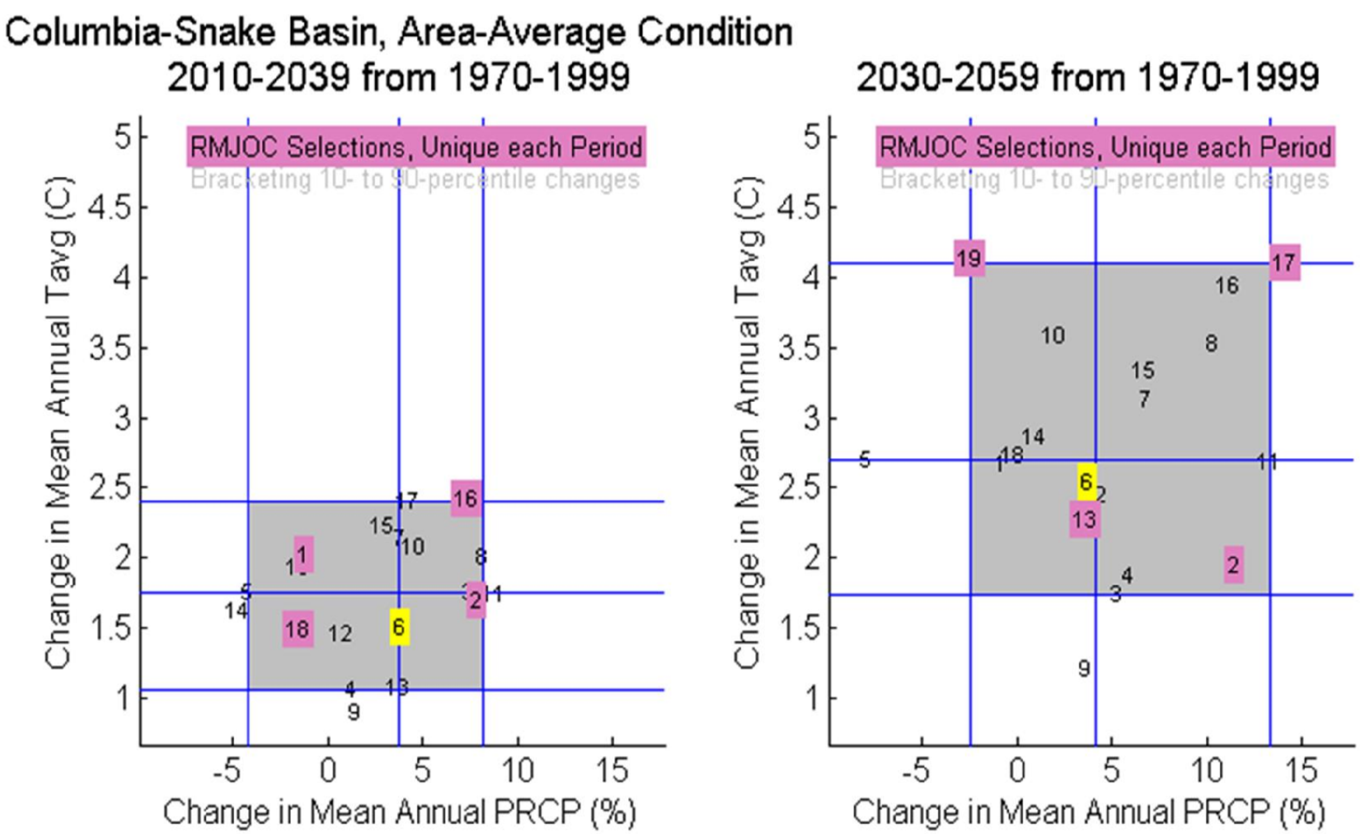
10 Climate Projections

7 Global Climate Models X **A1b and B1 emission scenarios**

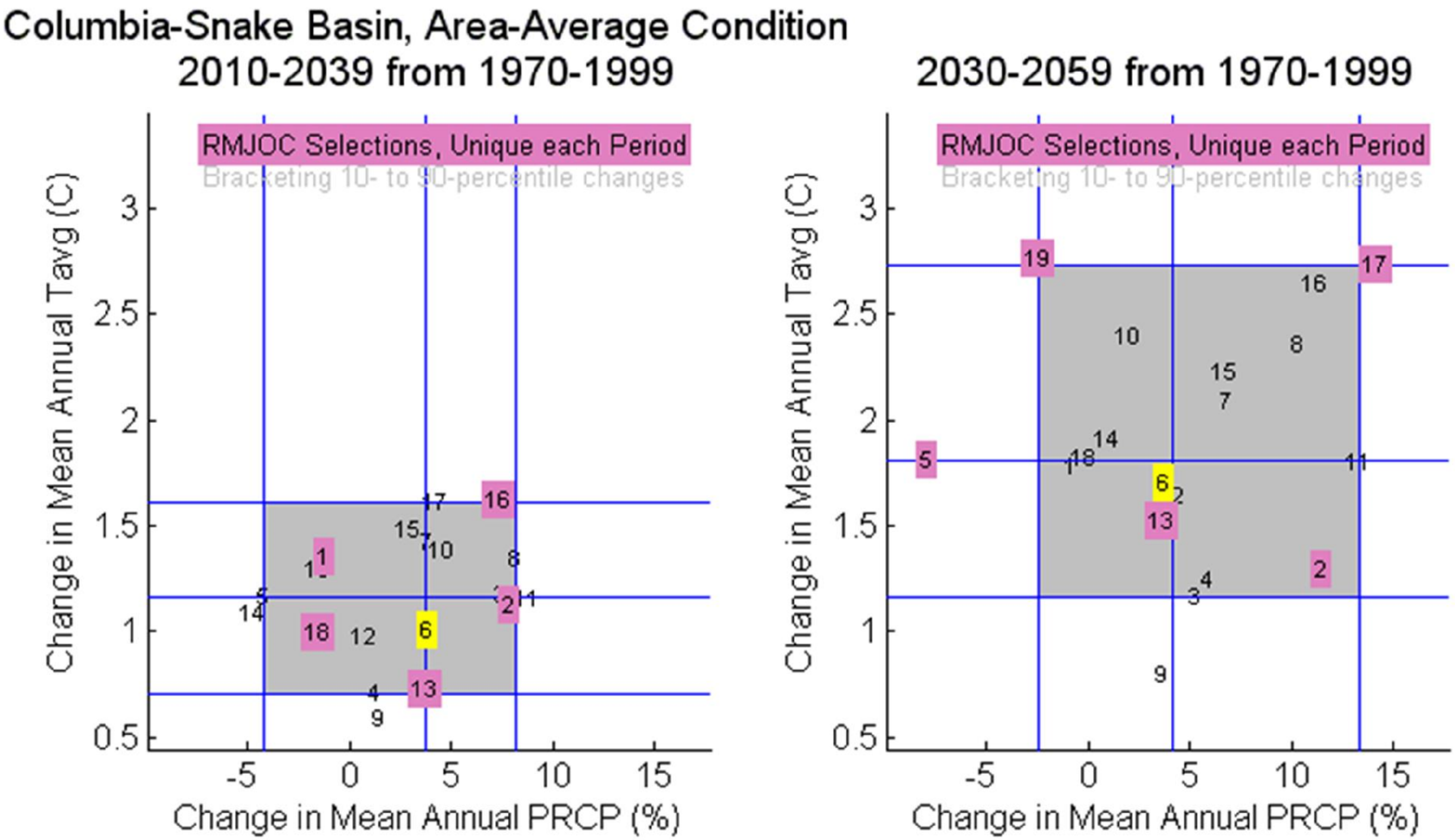
= 14 hydrologic "projections", continuous from historical to future (1950-2099) having Global Climate Model variability

How to select the scenarios…

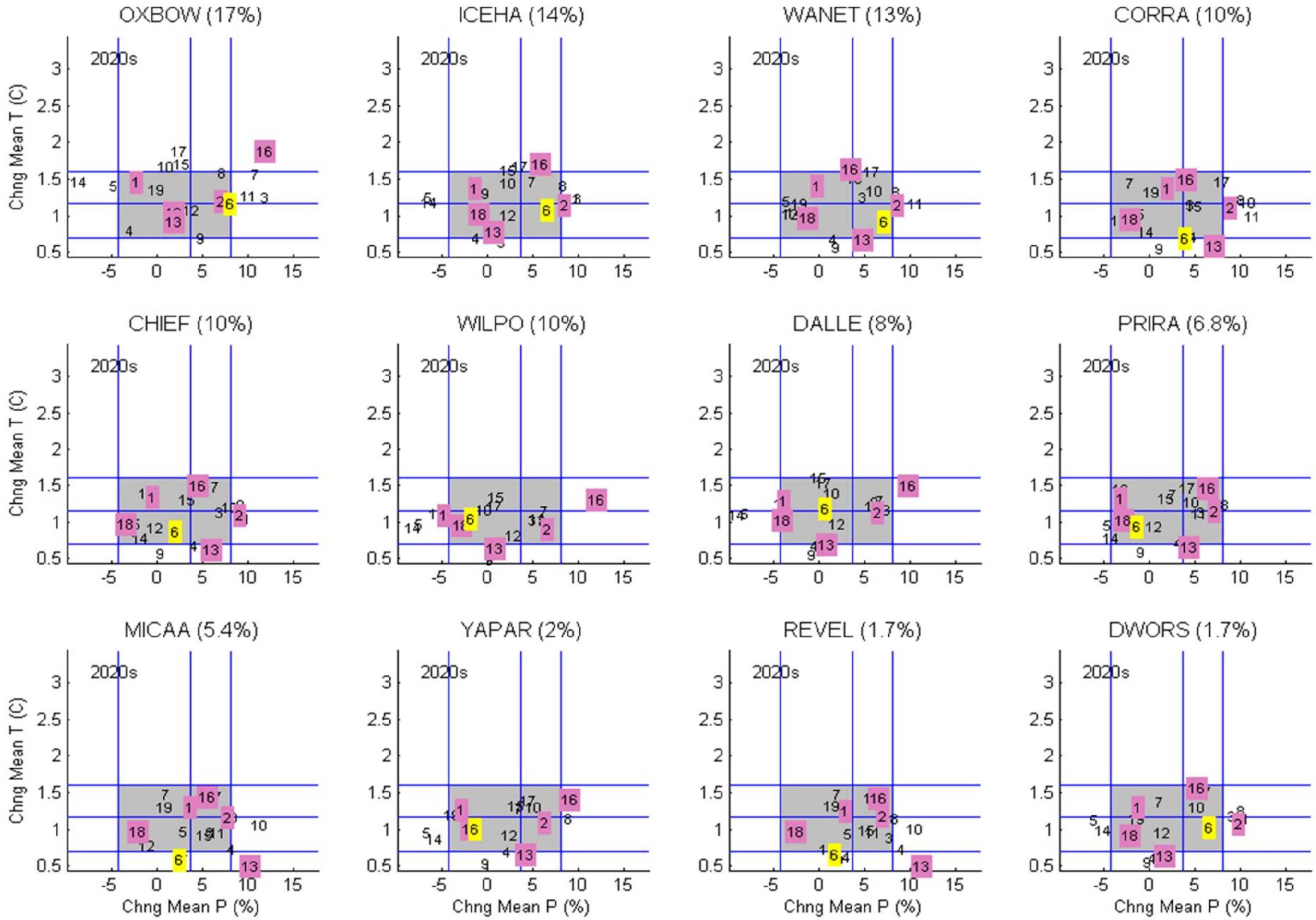
- 10 and 90 percentile brackets?
- 25 and 75 percentile brackets?
- Unique to each period?
- Based on which inflow points?



Selected Scenarios: The Dalles



Selected Scenarios: Sub-basins



Summary of Projections Selected

				Hybrid Selections						
				2020s			2040s			
Number		GCM [2]	Emissions Scenario	Selected (Labels) [3]	Change in P (in) [4]	Change in T (°C)	Selected (Labels)	Change in P (in)	Change in T (°C)	Transient (x = selected, o = not selected)
1	√	ccsm3	B1	MW/D	-1.2	1.4		-0.8	1.8	x
2	√	cgcm3.1 t47	B1	LW/W	7.9	1.1	LW/W	11.5	1.3	x
3		cnrm cm3	B1		7.5	1.2		5.3	1.2	o
4		echam5	B1		1.3	0.7		5.9	1.2	o
5	√	echo g	B1		-4.2	1.2	LW/D	-7.9	1.8	x
6	√	hadcm	B1	C	3.8	1.0	C	3.7	1.7	x
7		ipsl cm4	B1		3.8	1.4		6.9	2.1	
8		miroc 3.2	B1		8.1	1.3		10.4	2.3	
9		pcm1	B1		1.5	0.6		3.6	0.8	o
10		ccsm3	A1b		4.6	1.4		2.0	2.4	o
11		cgcm3.1 t47	A1b		8.8	1.2		13.4	1.8	o
12		cnrm cm3	A1b		0.8	1.0		4.1	1.6	o
13	√	echam5	A1b	MC	3.7	0.7	MC	3.7	1.5	x
14		echo g	A1b		-4.7	1.1		0.9	1.9	o
15		hadcm	A1b		3.0	1.5		6.7	2.2	o
16	√	ipsl cm4	A1b	MW/W	7.4	1.6		11.2	2.6	
17	√	miroc 3.2	A1b		4.2	1.6	MW/W	14.2	2.7	
18	√	pcm1	A1b	LW/D	-1.5	1.0		-0.2	1.8	x
19 [1]	√	hadgem1	A1b		-1.5	1.3	MW/D	-2.5	2.8	

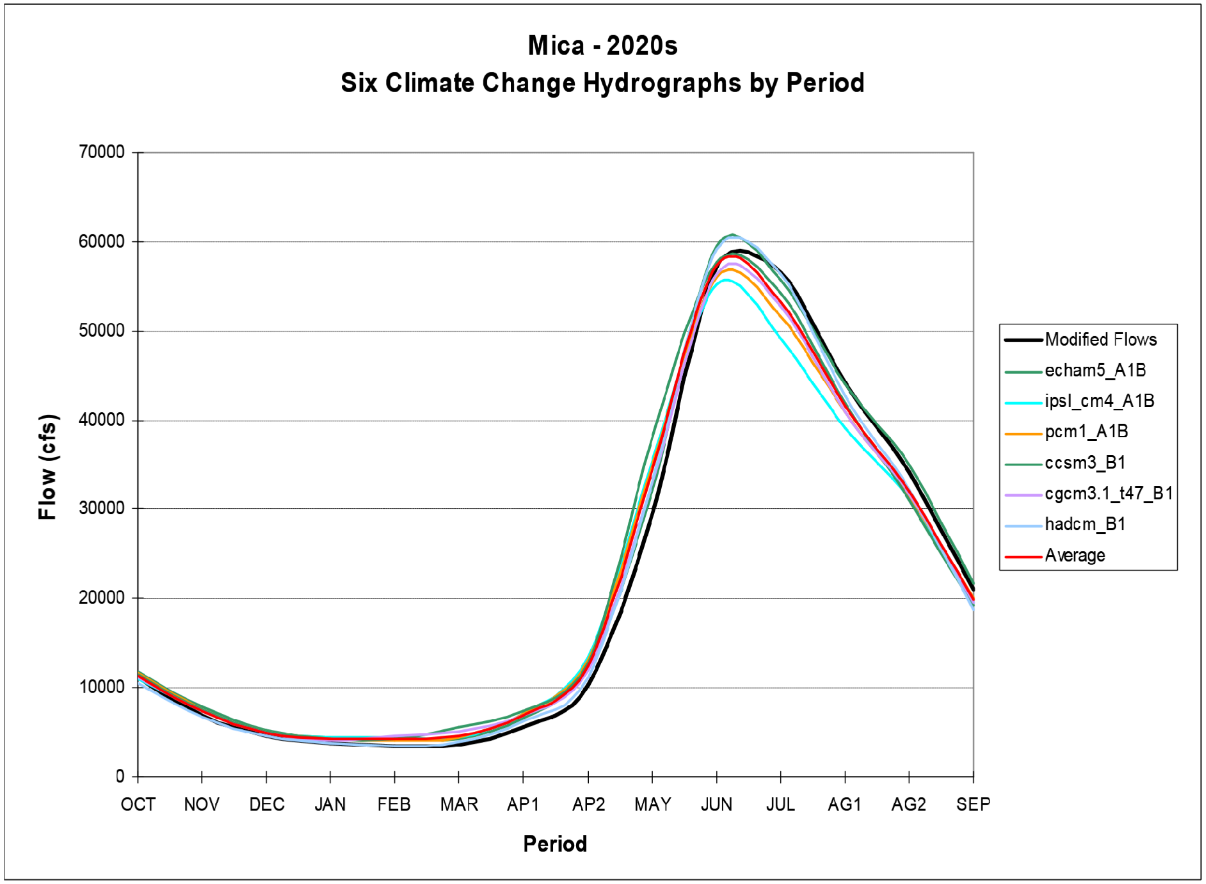
Notes

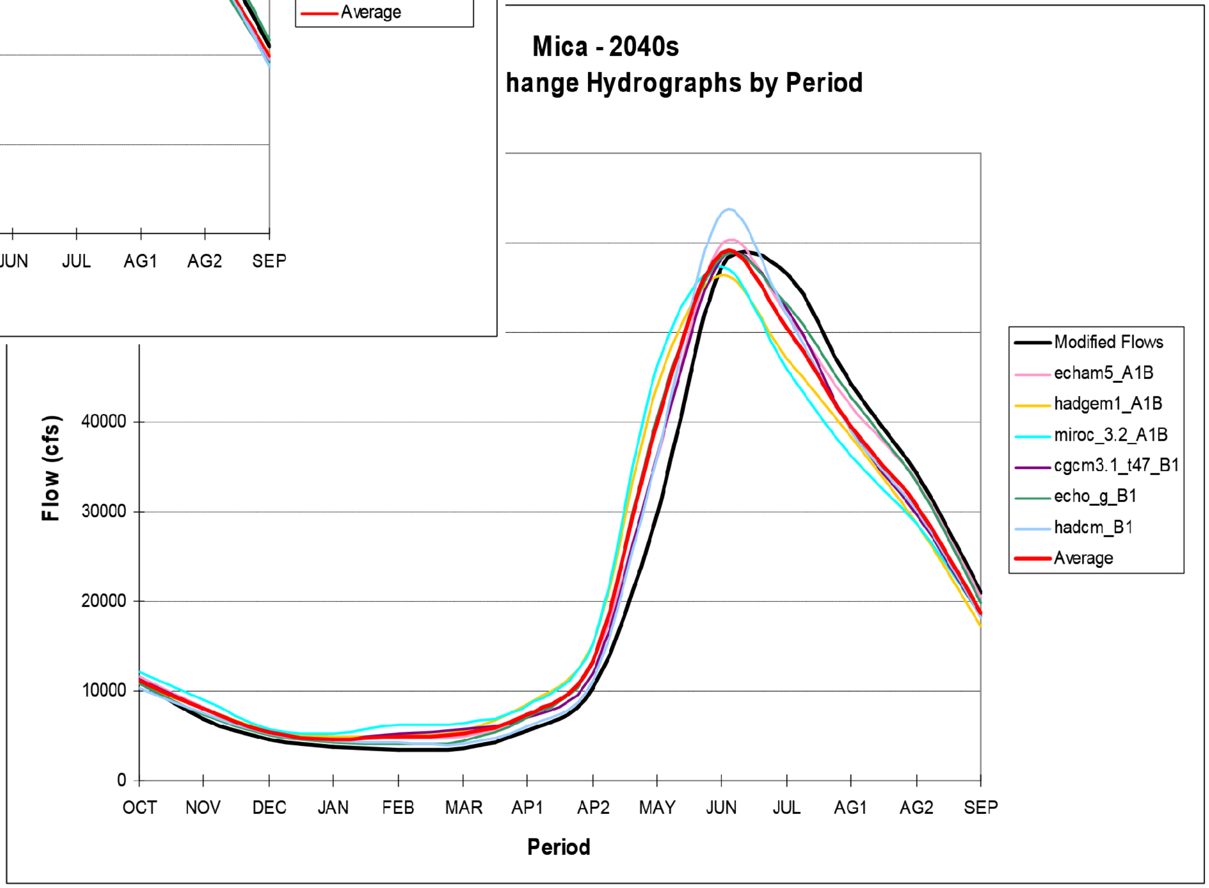
[1] Number 19 was not included in Oct 24 workbook shared with stakeholders.

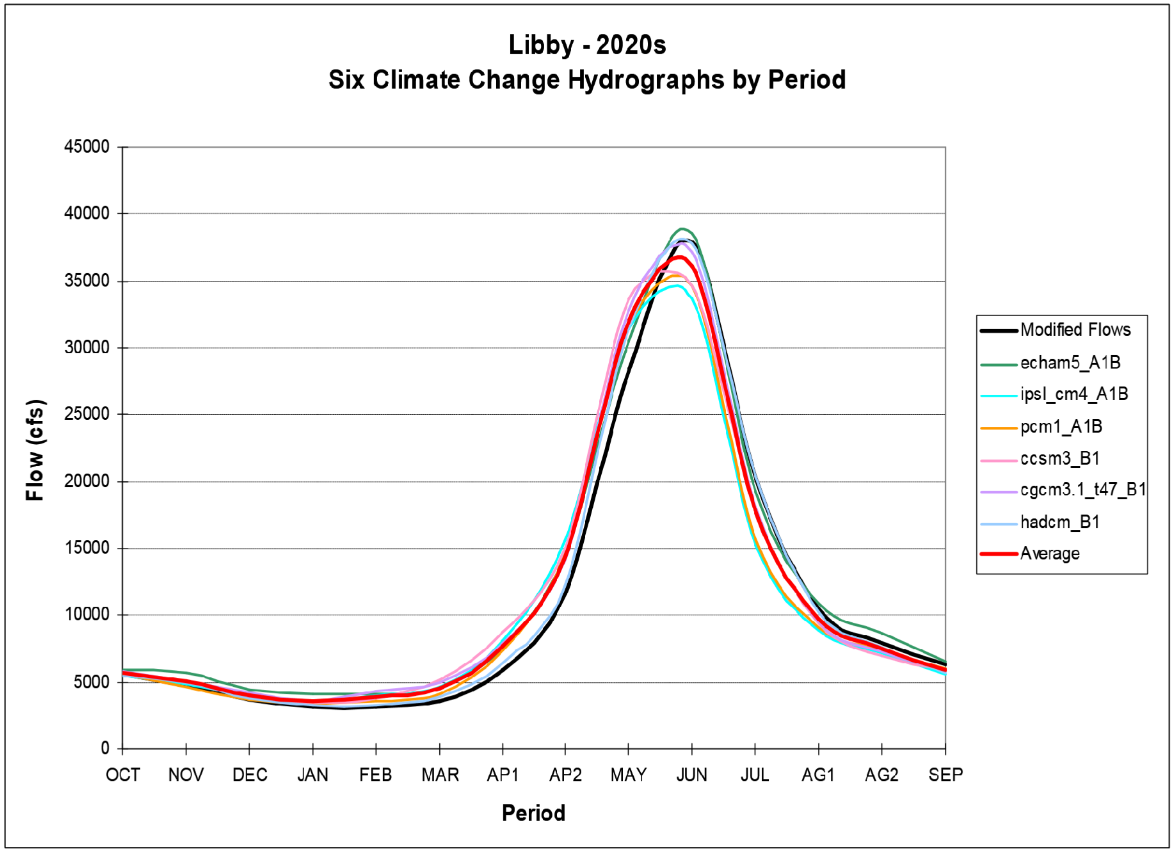
[2] Green shaded GCMs are those that BC Hydro suggested as being part of a "better set of GCMs." (Dec 2, Frank Weber email)

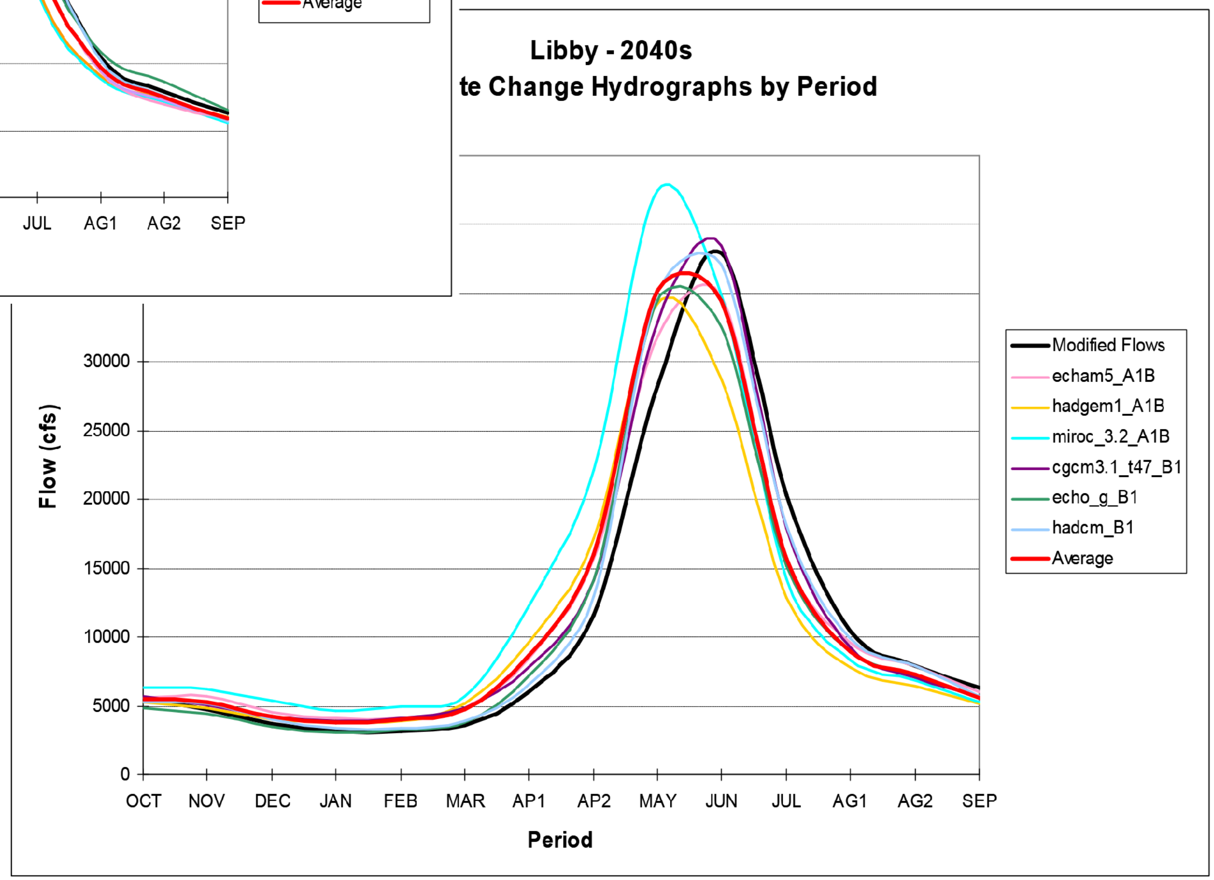
[3] Selected Labels: MW = More Warming, LW = Less Warming, W = Wetter, D = Drier, MC = Minor Change, C = Central Change

[4] P = precipitation, T = average daily temperature, "Change in" means change in 92-year period-mean annual condition. For assessing change, the reference is Observed Climate Variability, 1916-2006. The changed condition is the 92-year Observed Climate Variability sequence adjusted to match climate characteristics projected 30-year period (2020s = 2010-2039 and 2040s = 2030-2059) from the given underlying climate projection (column Number).


Mica - 2020s
Six Climate Change Hydrographs by Period
70000
60000
50000
40000
30000
20000
10000
0
Flow (cfs)
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average


Mica - 2040s
hange Hydrographs by Period
40000
30000
20000
10000
0
Flow (cfs)
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average


Libby - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average


Libby - 2040s
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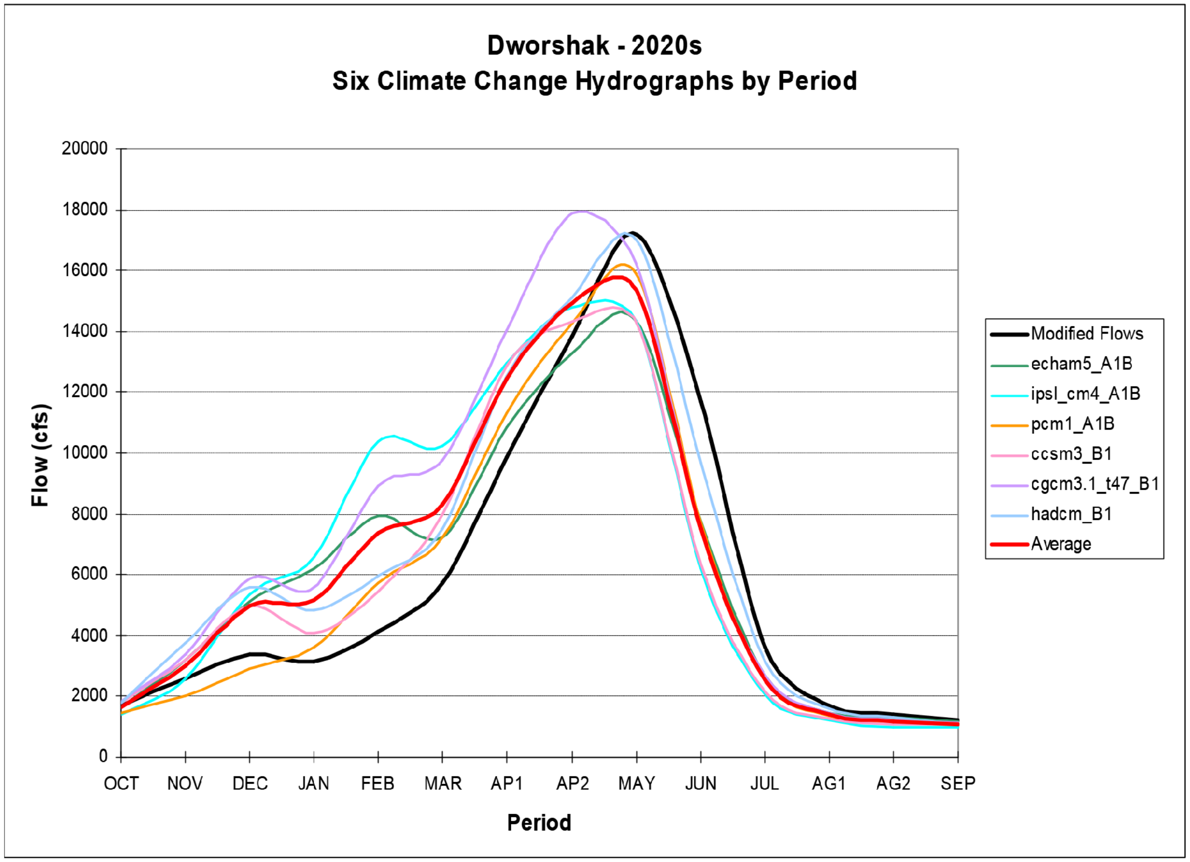
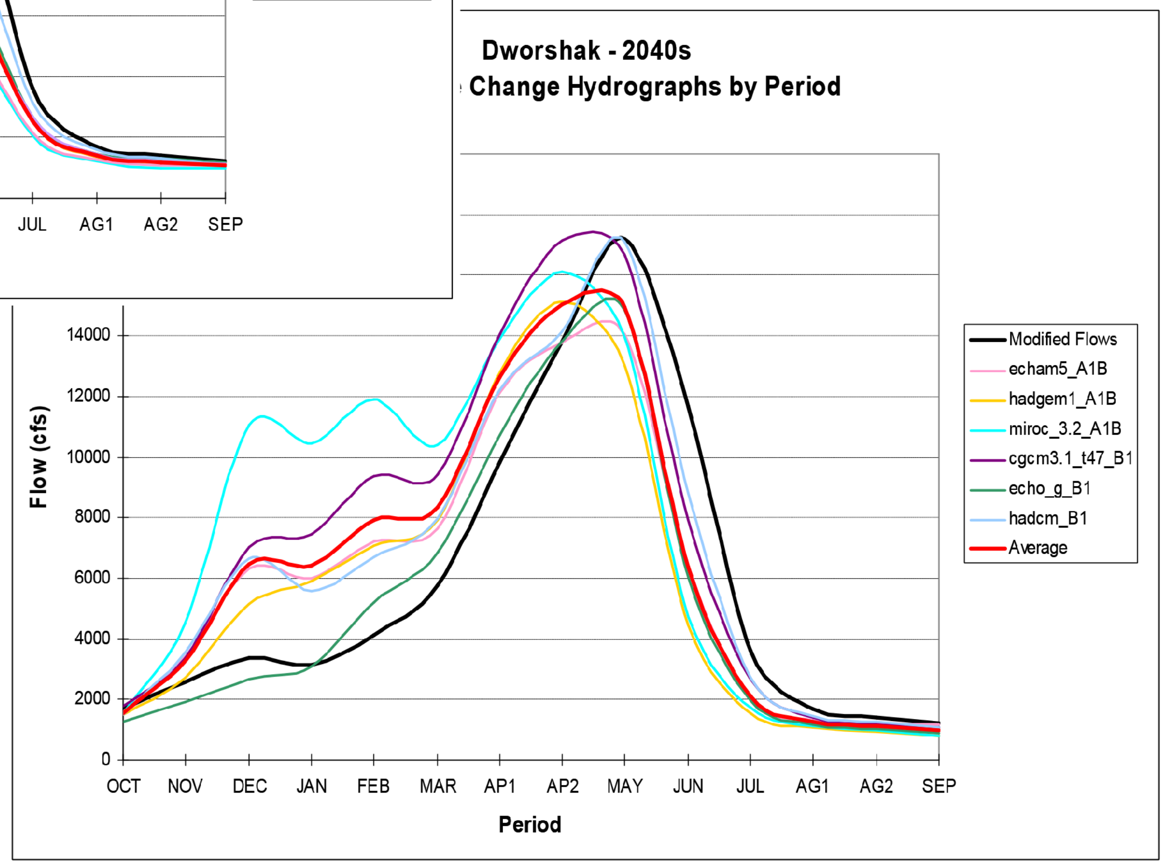
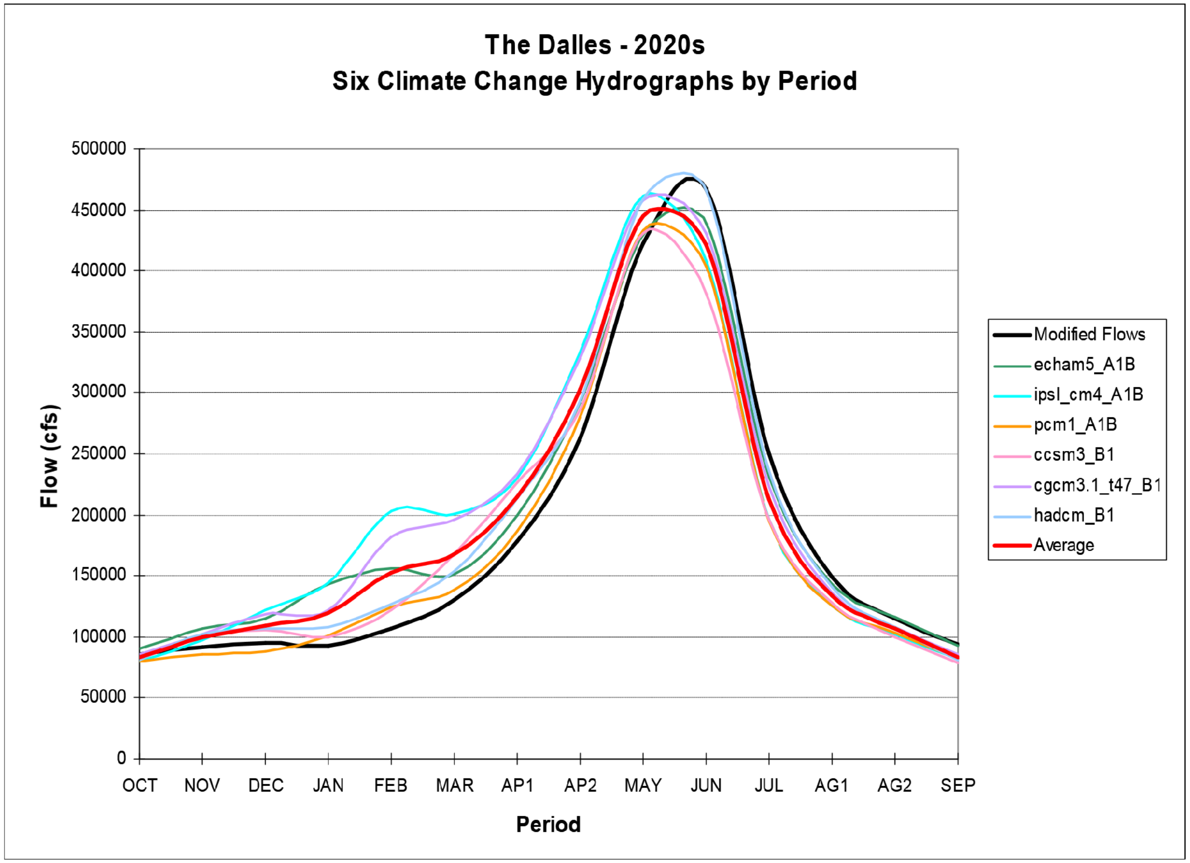
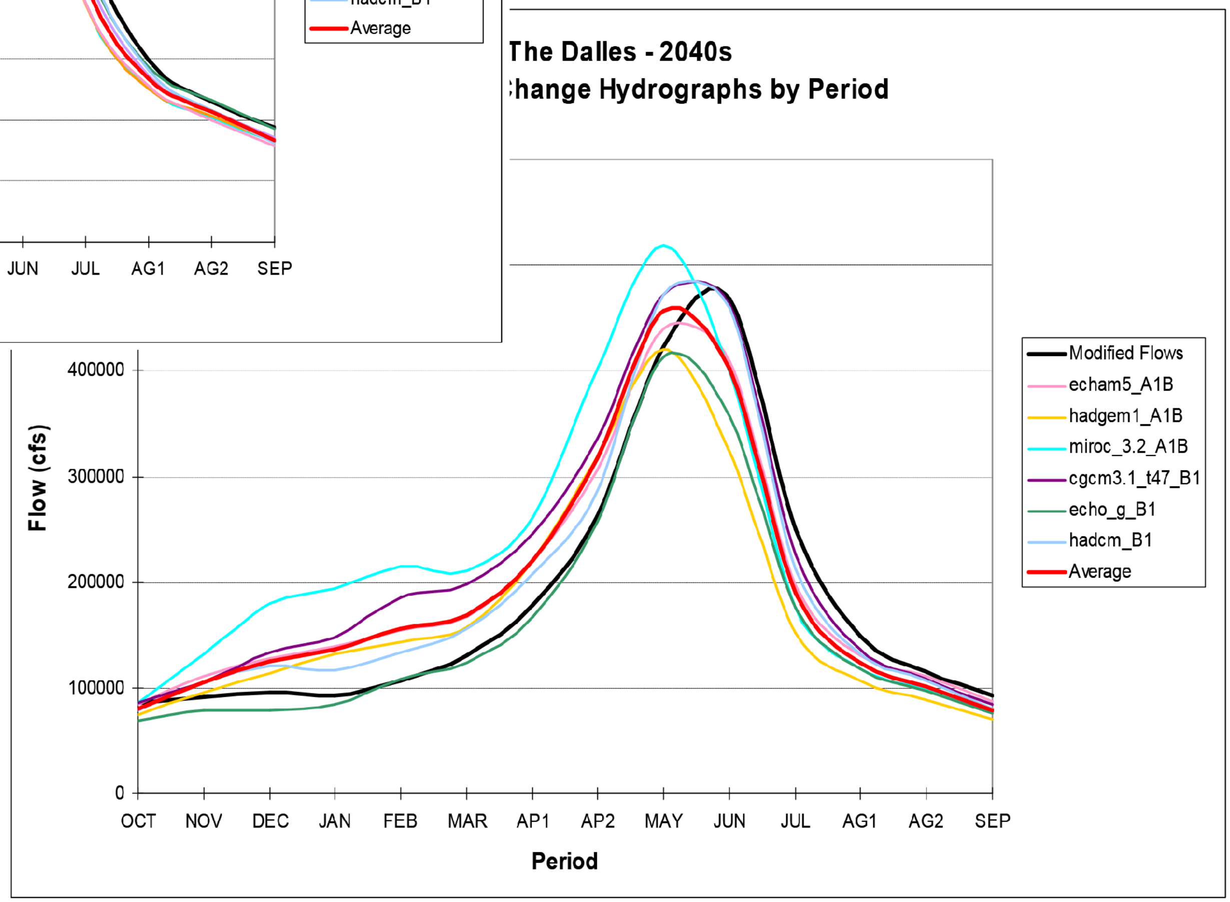
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average


Dworshak - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average


Dworshak - 2040s
Change Hydrographs by Period
Flow (cfs)
14000
12000
10000
8000
6000
4000
2000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average


The Dalles - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
OCT NOV DEC JAN FEB MAR AP1 AP2 MAY JUN JUL AG1 AG2 SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average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Flow (cfs)
400000
300000
200000
100000
0
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Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average

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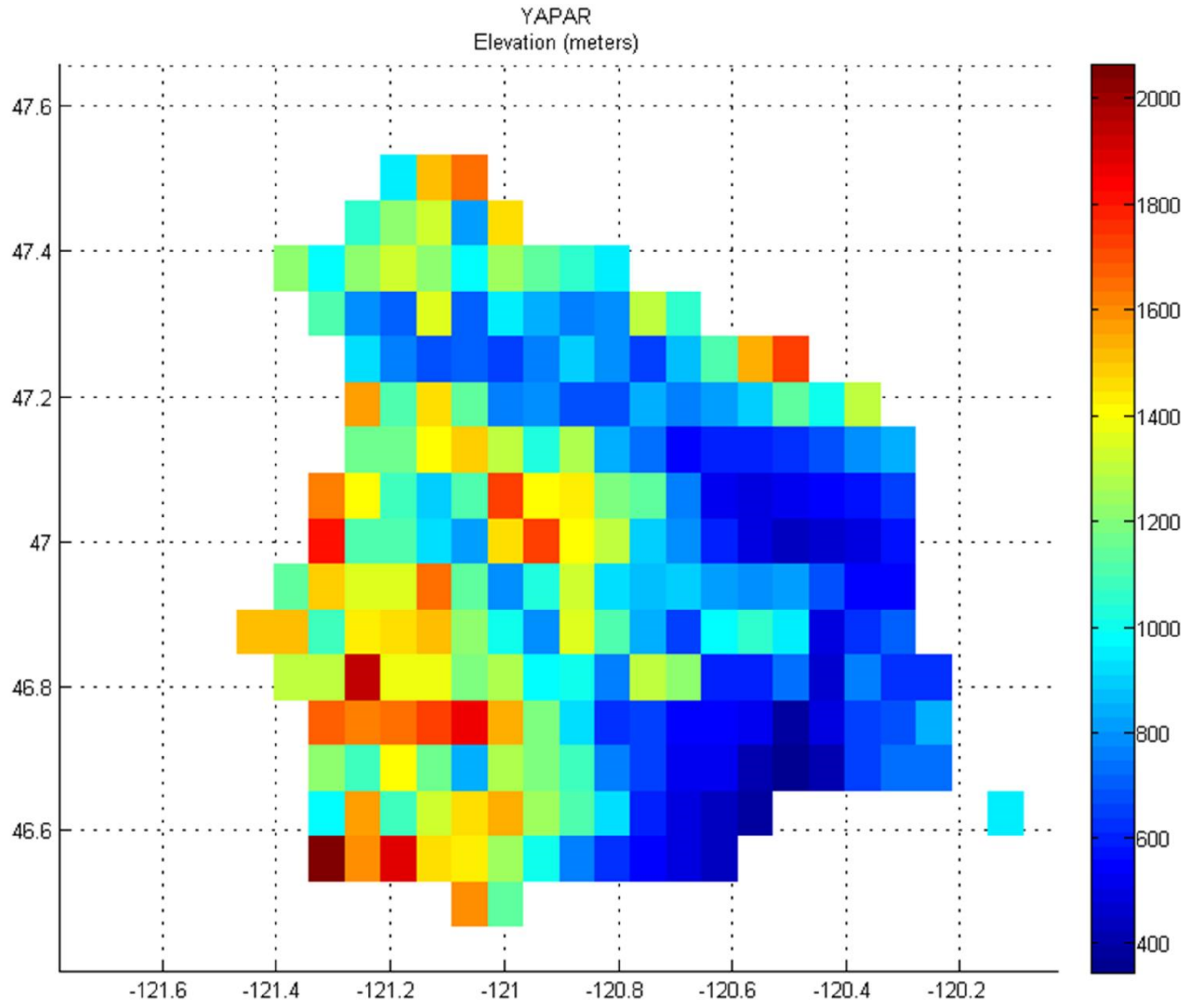
Synthetic Water Supply Forecasts



Deliverables

(#1) Subset of UW CIG Regional Climate Projection Information

- Step-change in climate ("hybrid")
- Time-developing climate ("transient")

(#2) Daily weather inputs for hydrologic modeling (both types)

(#3) Daily hydrologic modeling results (both types)

(#4) Streamflows bias-corrected or adjusted for reservoir operations/regulation modeling

(#5) Seasonal runoff volume forecasts

(#6) Develop Flood Control and Operating Rule Curves

(#7) Demonstration Study by RMJOC agencies' staff

Collaborative Workshops

June 9, 2009
October 16, 2009
December 7, 2009
April 19, 2010

- Corps (Districts and Division)
- BPA
- BOR
- CIG
- NWRFC
- FWS
- NOAA Fisheries
- Columbia River Inter-Tribal Fish Commission
- Northwest Power and Conservation Council
- NRCS
- BC Hydro
- OCCRI

Applications in Next 1-3 Years

- 2014/2024 Columbia River Treaty Review
- NEPA
- Bi-Op Studies
- Flood Risk Management (Corps)
- NPCC Power Plan

RMJOC Climate and Hydrology Dataset for Use in Agencies' Longer-Term Planning Studies

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*River Management Joint Operating Committee

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Idaho Department of Water Resources
USBR, Boise Regional Office
USACE, Seattle and Portland Districts

Data from CIG Effort

- Develop historic driving meteorological data at 1/16th degree (7 kilometer) from 1915- 2005
- Produce downscaled 1/16th degree driving data sets associated with each of 10 General Circulation Model (GCM) scenarios for "2020" "2050" "2080" time periods
- Run the 1/16th degree Variable Infiltration Capacity (VIC) hydrologic model for each of 10 GCM scenarios for the three time periods, and produce streamflow scenarios for over 200 inflow locations
- Adjust natural flow scenarios to estimate monthly Modified Flows for all Hydsim sites

Project Status

TASK	STATUS
1.1 Review of Climate Projection Information from US CIG	COMPLETE
1.2 Selection of Subset	COMPLETE
1.3 Documentation and Internal Review	In progress (2/3)
2.1 Obtain/review hydrologic mode (VIC)	COMPLETE
2.2 Obtain and review daily weather inputs	COMPLETE
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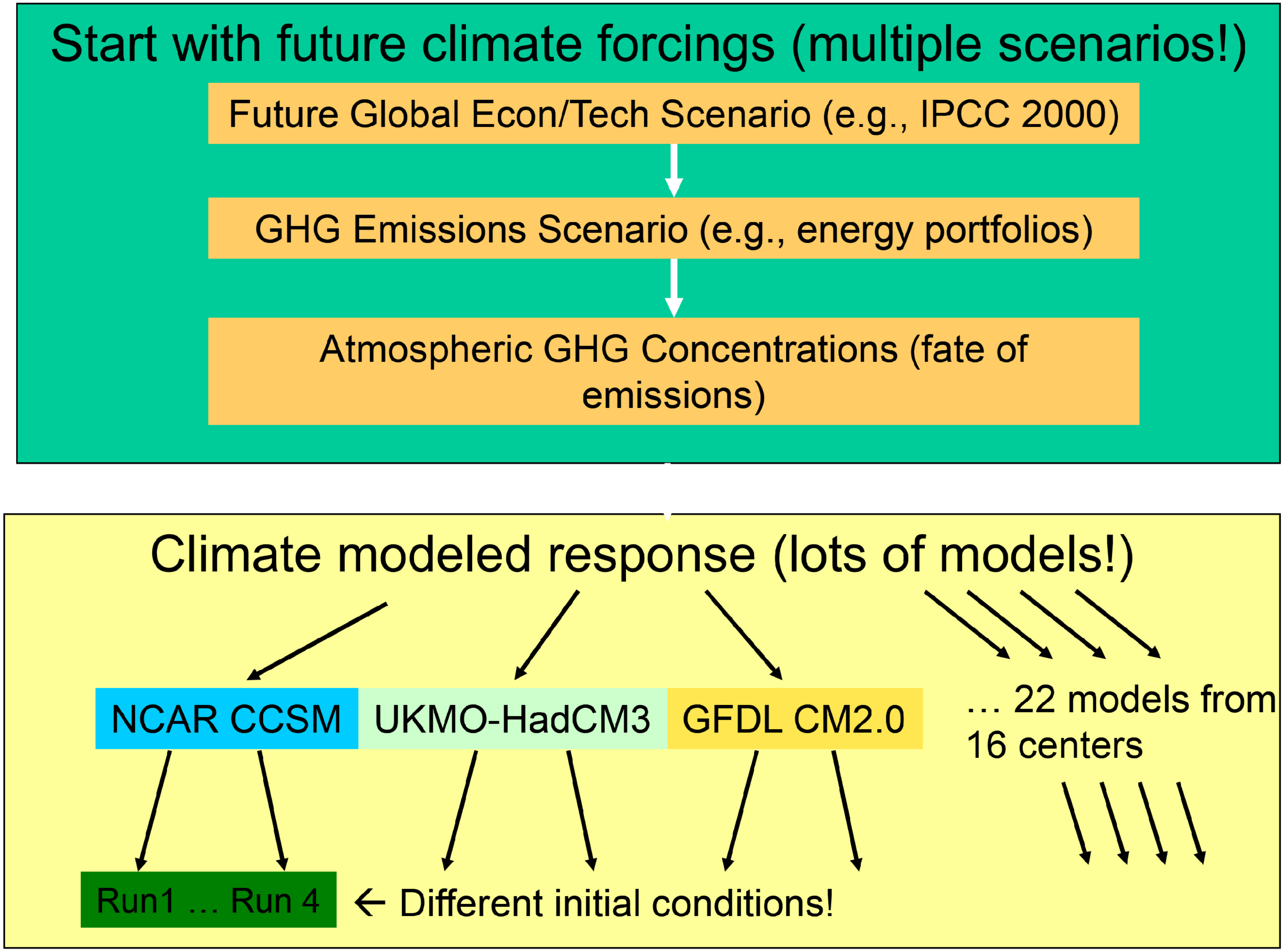
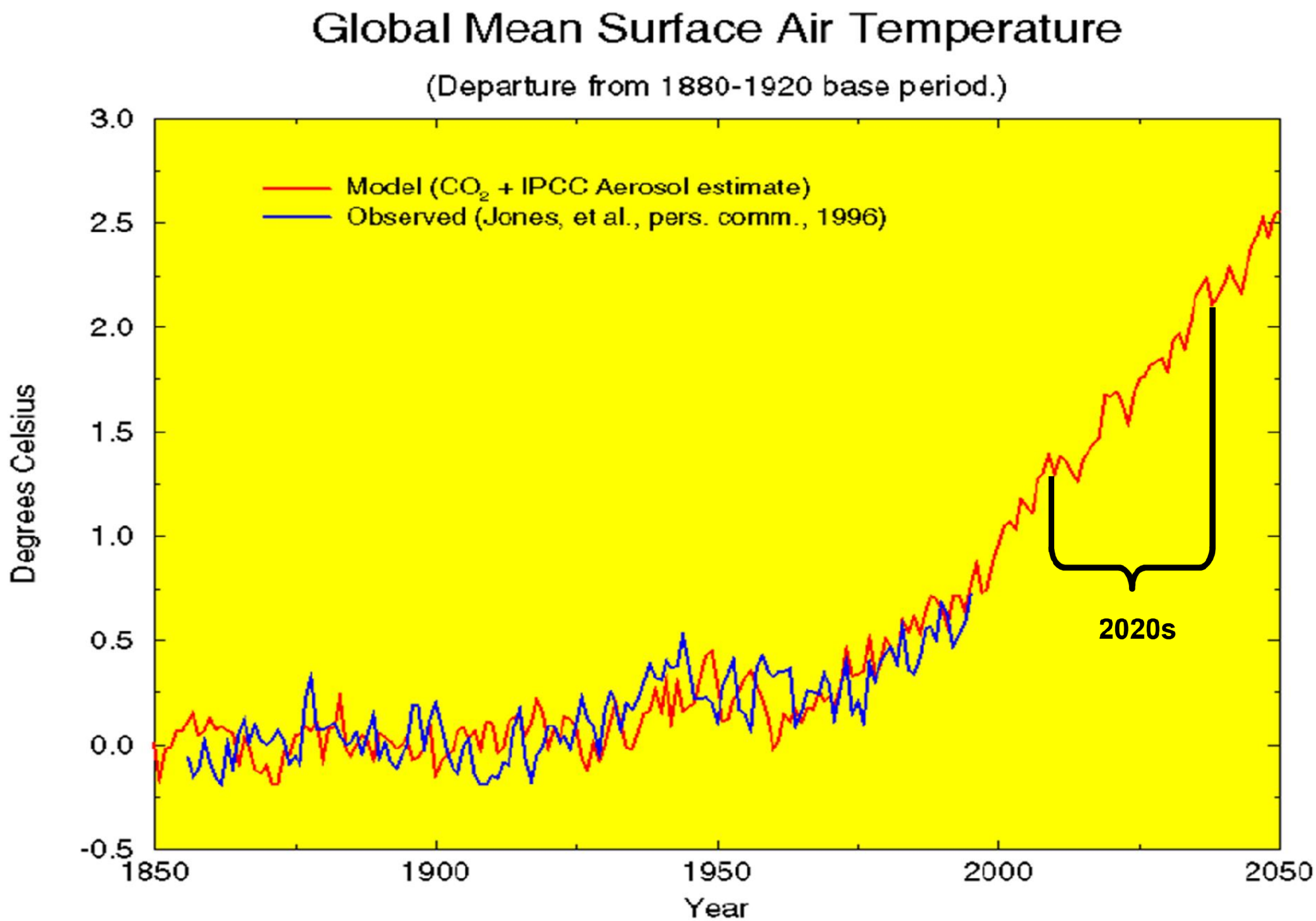
3.0 Bias-correct CIG data for BOR inputs	COMPLETE
3.1 Prepare Inflows (incorporate BOR inflows)	In progress
3.2 Prepare seasonal runoff volume forecasts	Waiting on 3.1
3.3 Compute FC targets and VECC	Waiting on 3.1, 3.2
3.4 Demonstration Analyses	Prepping and waiting on 3.1, 3.2, 3.3

More than just a few choices…



Courtesy: Barsugli


Global Mean Surface Air Temperature
(Departure from 1880-1920 base period.)
Model (CO_2 + IPCC Aerosol estimate)
Observed (Jones, et al., pers. comm., 1996)
Degrees Celsius
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1850
1900
1950
2000
2050
Year
2020s

What subsets are appropriate for planning purposes? Which data type is best for each planning study?

"*Hybrid-Delta*" or step-change data ("climate change")

20 Climate Projections

10 Global Climate Models X **A1b and B1 emission scenarios**

X **sampled changes from 1971-2000 to either… 2010-2039 2040-2069**

= 40 "climate change" hydrologic scenarios, each 92 years in duration, having variability as observed from 1915-2006

"*Transient*" or time-developing

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= 14 hydrologic "projections", continuous from historical to future (1950-2099), having Global Climate Model variability

How to select the scenarios…

- 10 and 90 percentile brackets?
- 25 and 75 percentile brackets?
- Unique to each period?
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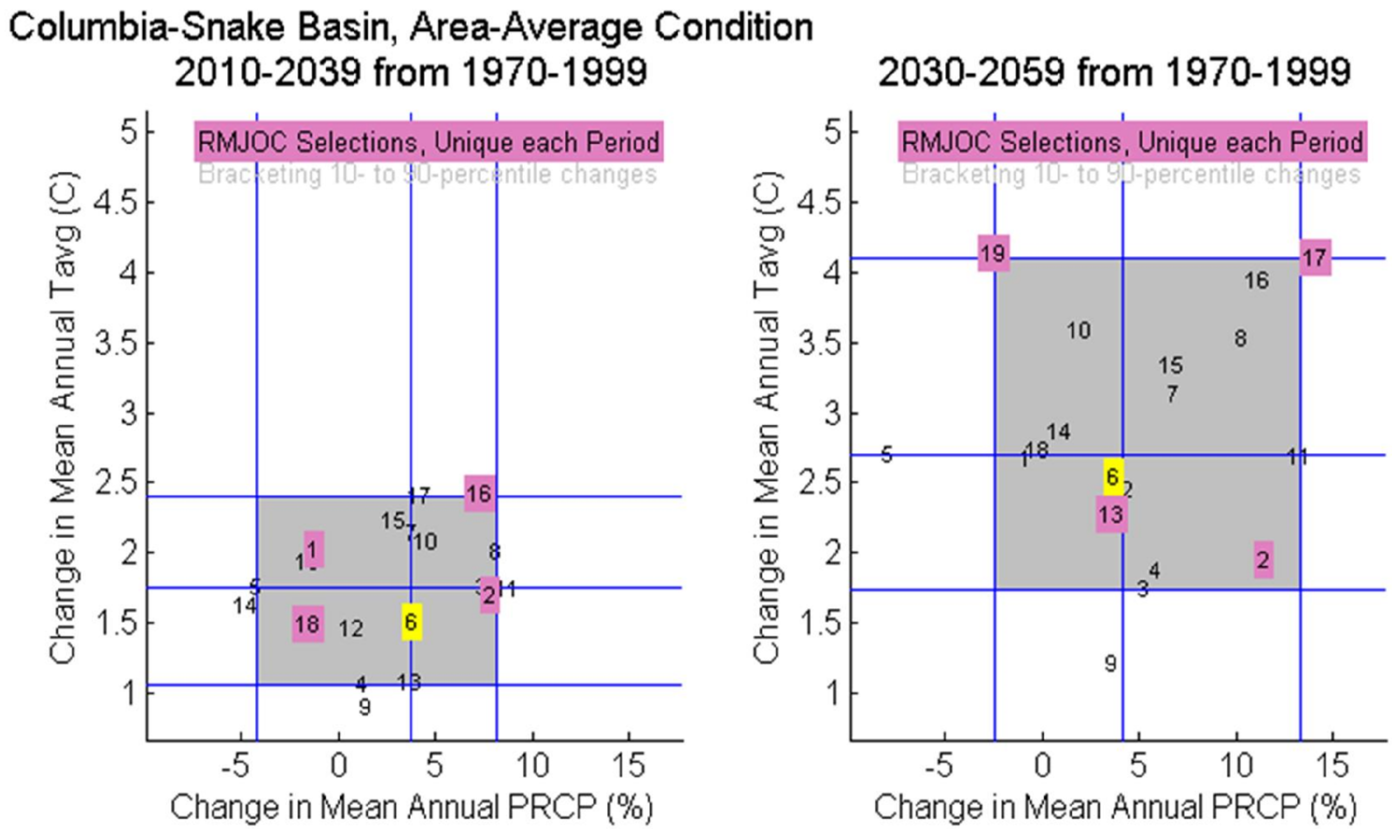
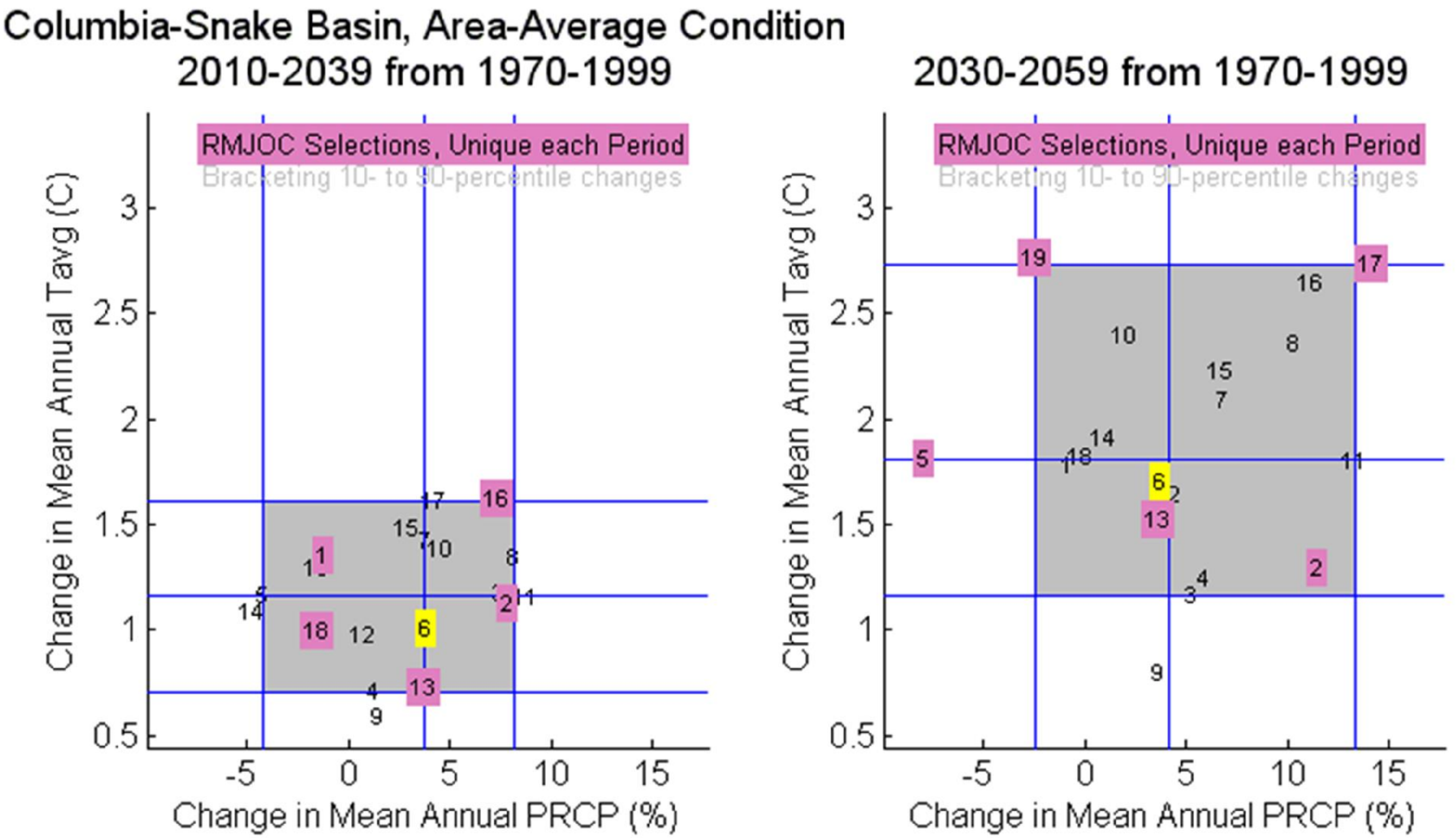
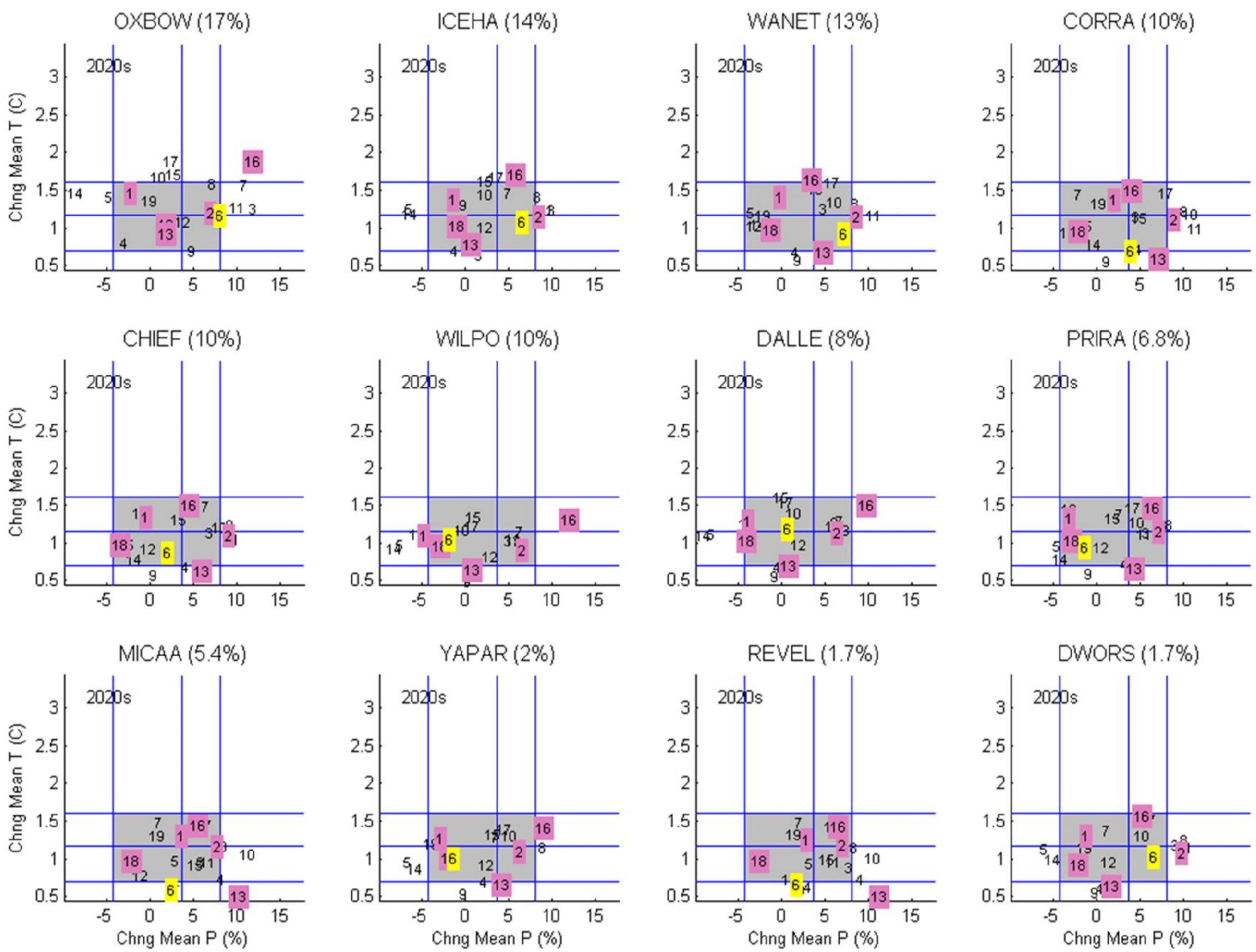


Selected Scenarios: The Dalles



Selected Scenarios: Sub-basins



Summary of Projections Selected

				Hybrid Selections						
				2020s			2040s			
Number		GCM [2]	Emissions Scenario	Selected (Labels) [3]	Change in P (in) [4]	Change in T (°C)	Selected (Labels)	Change in P (in)	Change in T (°C)	Transient (x = selected, o = not selected)
1	√	ccsm3	B1	MW/D	-1.2	1.4		-0.8	1.8	x
2	√	cgcm3.1 t47	B1	LW/W	7.9	1.1	LW/W	11.5	1.3	x
3		cnrm cm3	B1		7.5	1.2		5.3	1.2	o
4		echam5	B1		1.3	0.7		5.9	1.2	o
5	√	echo g	B1		-4.2	1.2	LW/D	-7.9	1.8	x
6	√	hadcm	B1	C	3.8	1.0	C	3.7	1.7	x
7		ipsl cm4	B1		3.8	1.4		6.9	2.1	
8		miroc 3.2	B1		8.1	1.3		10.4	2.3	
9		pcm1	B1		1.5	0.6		3.6	0.8	o
10		ccsm3	A1b		4.6	1.4		2.0	2.4	o
11		cgcm3.1 t47	A1b		8.8	1.2		13.4	1.8	o
12		cnrm cm3	A1b		0.8	1.0		4.1	1.6	o
13	√	echam5	A1b	MC	3.7	0.7	MC	3.7	1.5	x
14		echo g	A1b		-4.7	1.1		0.9	1.9	o
15		hadcm	A1b		3.0	1.5		6.7	2.2	o
16	√	ipsl cm4	A1b	MW/W	7.4	1.6		11.2	2.6	
17	√	miroc 3.2	A1b		4.2	1.6	MW/W	14.2	2.7	
18	√	pcm1	A1b	LW/D	-1.5	1.0		-0.2	1.8	x
19 [1]	√	hadgem1	A1b		-1.5	1.3	MW/D	-2.5	2.8	

Notes

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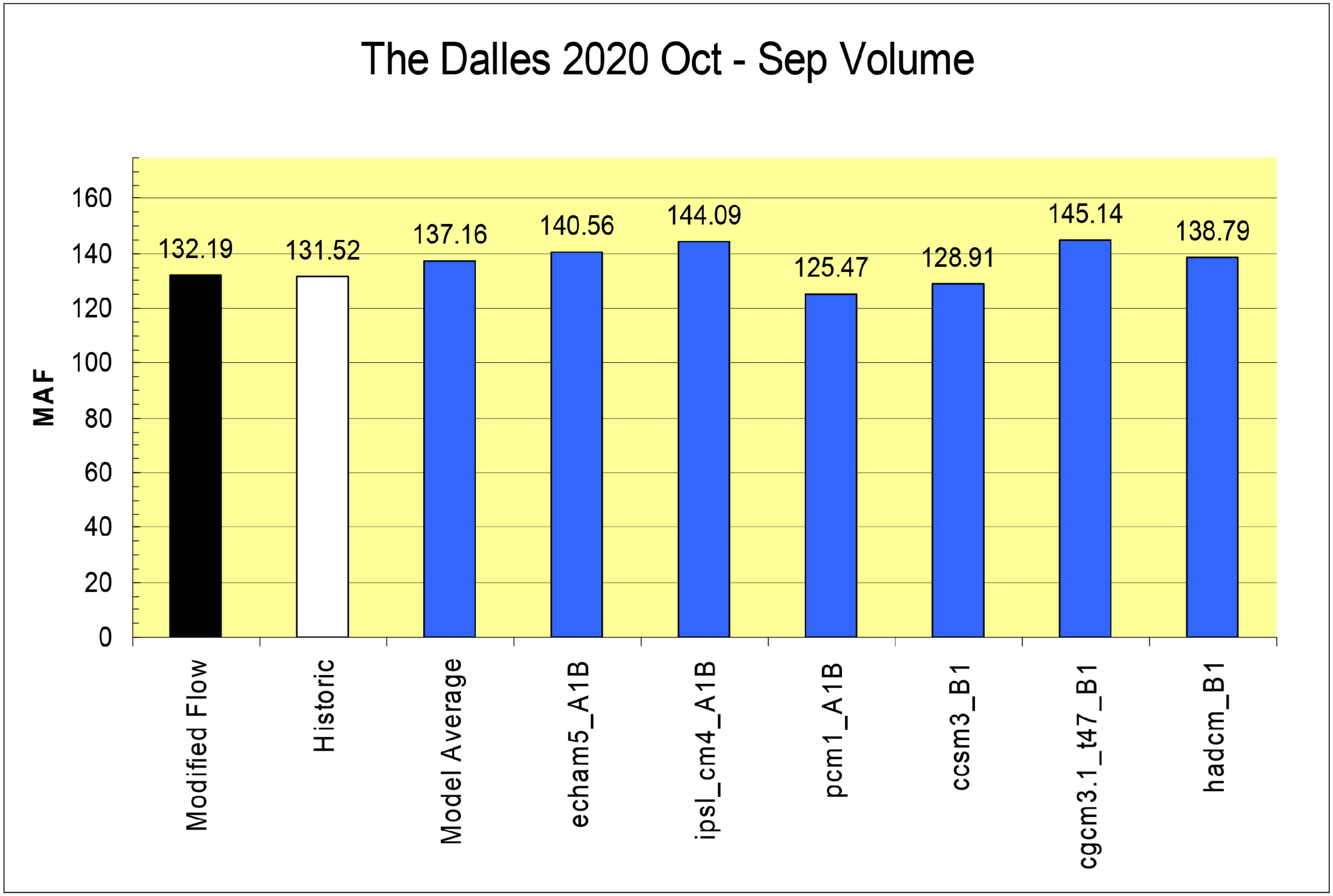
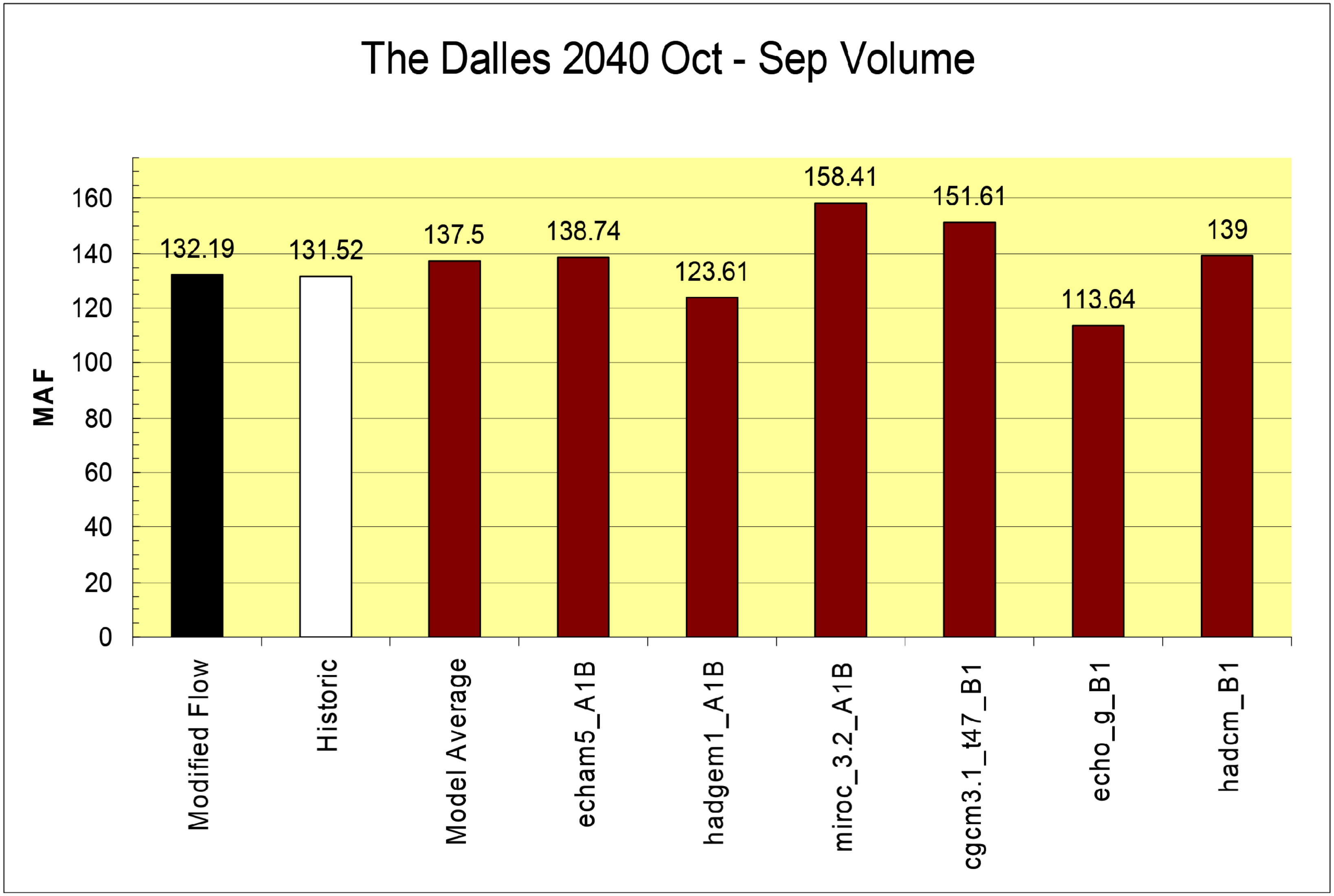
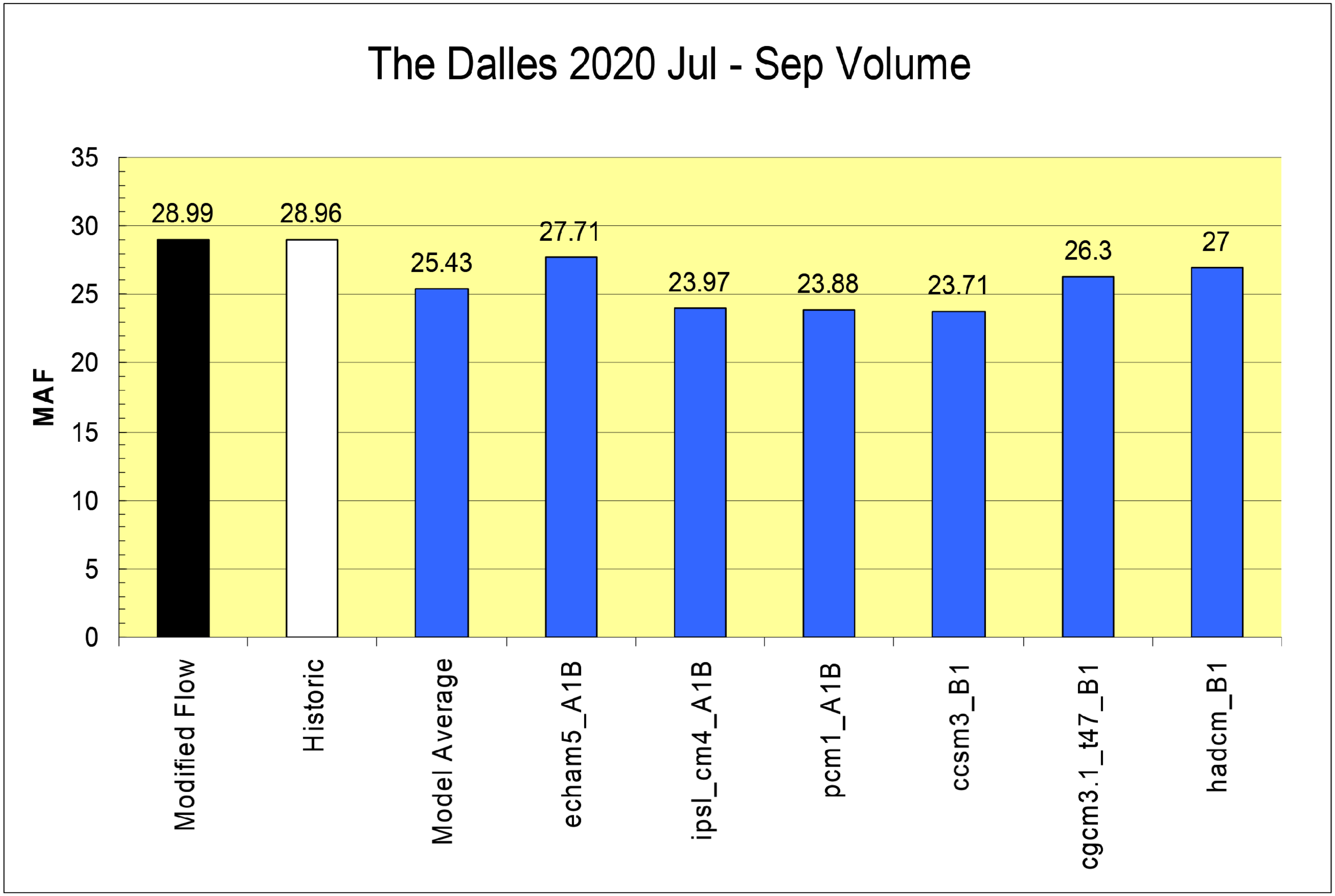
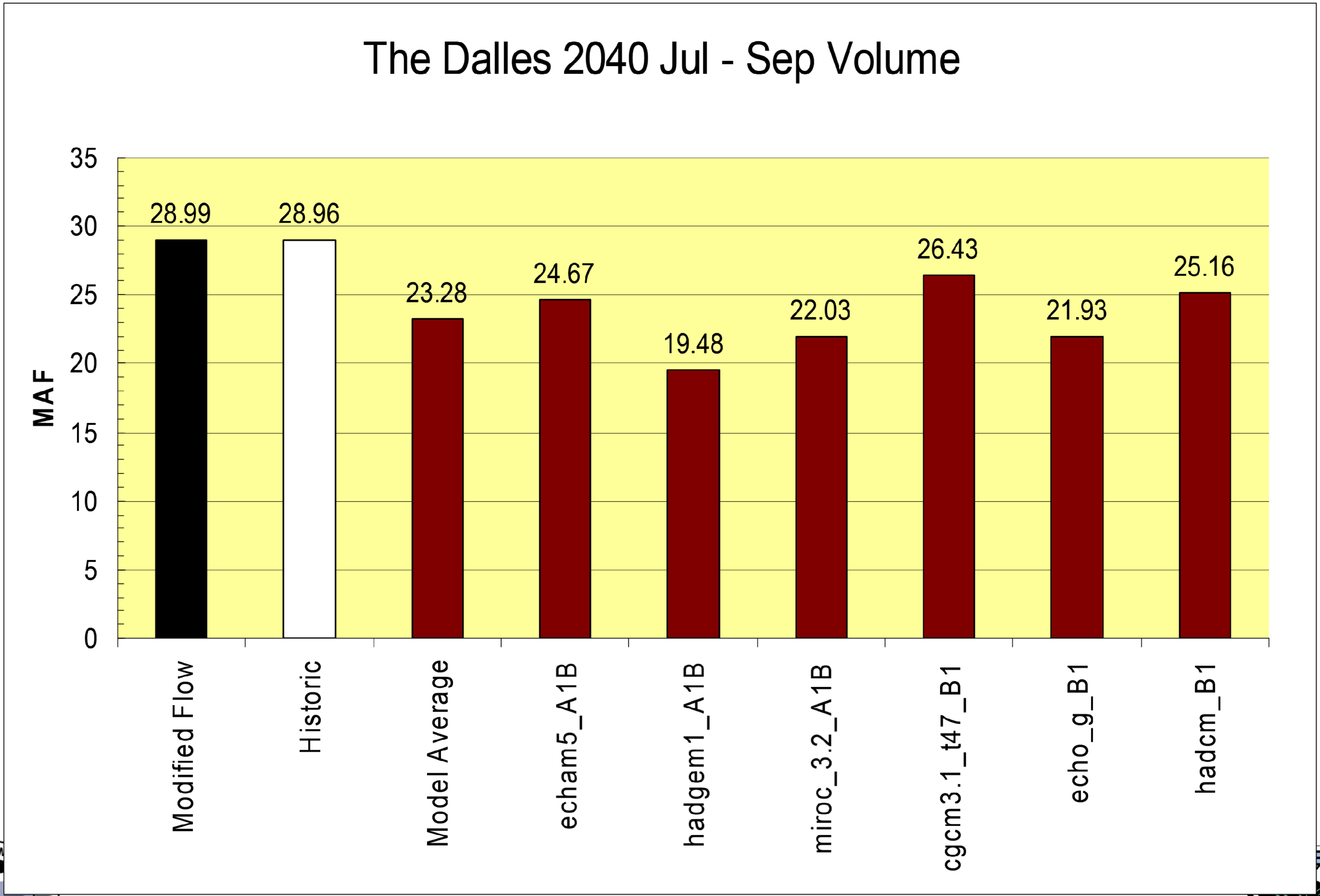

The Dalles 2020 Oct - Sep Volume
MAF
0
20
40
60
80
100
120
140
160
132.19
131.52
137.16
140.56
144.09
125.47
128.91
145.14
138.79
Modified Flow
Historic
Model Average
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1


The Dalles 2040 Oct - Sep Volume
MAF
0
20
40
60
80
100
120
140
160
132.19
131.52
137.5
138.74
123.61
158.41
151.61
113.64
139
Modified Flow
Historic
Model Average
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1


The Dalles 2020 Jul - Sep Volume
MAF
35
30
25
20
15
10
5
0
28.99
28.96
25.43
27.71
23.97
23.88
23.71
26.3
27
Modified Flow
Historic
Model Average
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1



The Dalles 2040 Jul - Sep Volume
MAF
35
30
25
20
15
10
5
0
28.99
28.96
23.28
24.67
19.48
22.03
26.43
21.93
25.16
Modified Flow
Historic
Model Average
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1

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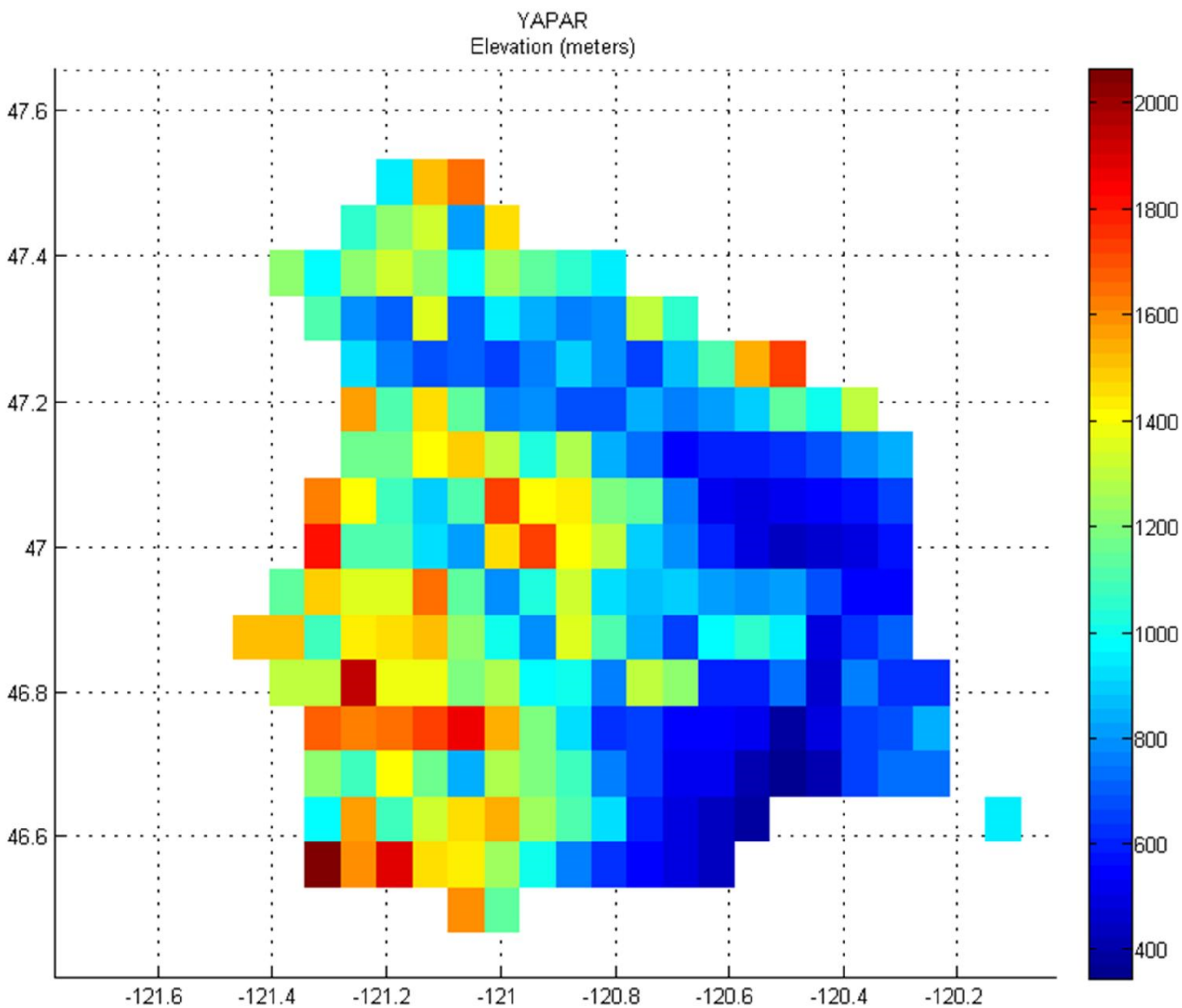
Synthetic Water Supply Forecasts



Collaborative Workshops

June 9, 2009
October 16, 2009
December 7, 2009
April 19, 2010

- Corps (Districts and Division)
- BPA
- BOR
- CIG
- NWRFC
- FWS
- NOAA Fisheries
- Columbia River Inter-Tribal Fish Commission
- Northwest Power and Conservation Council
- NRCS
- BC Hydro
- OCCRI

Applications in Next 1-3 Years

- 2014/2024 Columbia River Treaty Review
- NEPA
- Bi-Op Studies
- Flood Risk Management (Corps)
- NPCC Power Plan

RMJOC

RMJOC Climate and Hydrology Dataset for use in Agencies' Longer-Term Planning Studies

PNUCC Board Meeting

August 6th, 2010

Seshu Vaddey

U.S. Army Corps of Engineers, Portland District

Nancy Stephan

Bonneville Power Administration

FCRPS
FEDERAL COLUMBIA RIVER POWER SYSTEM
RMJOC

RMJOC

- The Joint Operating Committee **(JOC)** was established through the Direct Funding Memorandum of Agreements (MOAs) between BPA, Reclamation, and the Corps for the asset planning, maintenance, and operation of the FCRPS.
- The River Management Joint Operating Committee **(RMJOC)** is a sub-committee specifically dedicated to reviewing the practices, procedures, and processes of each Agency to identify changes that could improve the overall efficiency of the operation and management of the FCRPS projects.

RMJOC

RMJOC Motive and Need

- Motive
  - consistent incorporation of climate projection information into Agencies' longer-term planning studies

- Need
  - adopt common dataset (climate and hydrology)
  - establish consensus methods for data use
  - efficiently use limited resources through coordinated development of data and methods

RMJOC

Key Scoping Decisions

1. Start with existing CIG's data on regional climate and hydrology (CIG's "HB2860" regional project)

2. Use two methodologies from CIG
   - Step-change climate information (Hybrid-Delta)
   - Time-developing climate information (Transient)

3. Use only a subset of both data sets

4. Conduct modeling and analysis using both types (Hybrid-Delta and Transient) to look at overall climate change impacts and draw impressions on which types might be more appropriate for various types of Agencies' longer-term planning

RMJOC

Original Data from CIG Effort

- **Develop historic meteorological data at 1/16th degree (7 kilometer) from 1915- 2005**
- **Developed downscaled 1/16th degree meteorological data sets associated with each of 10 GCM scenarios for "2020s" "2050s" "2080s" time periods**
- **Run the 1/16th degree VIC hydrologic model for each of 10 GCM scenarios for the three time periods, and produce streamflow scenarios for over 200 inflow locations**
- **Bias adjust natural flow scenarios to estimate monthly Modified Flows for all Hydsim and Genesys sites**

RMJOC

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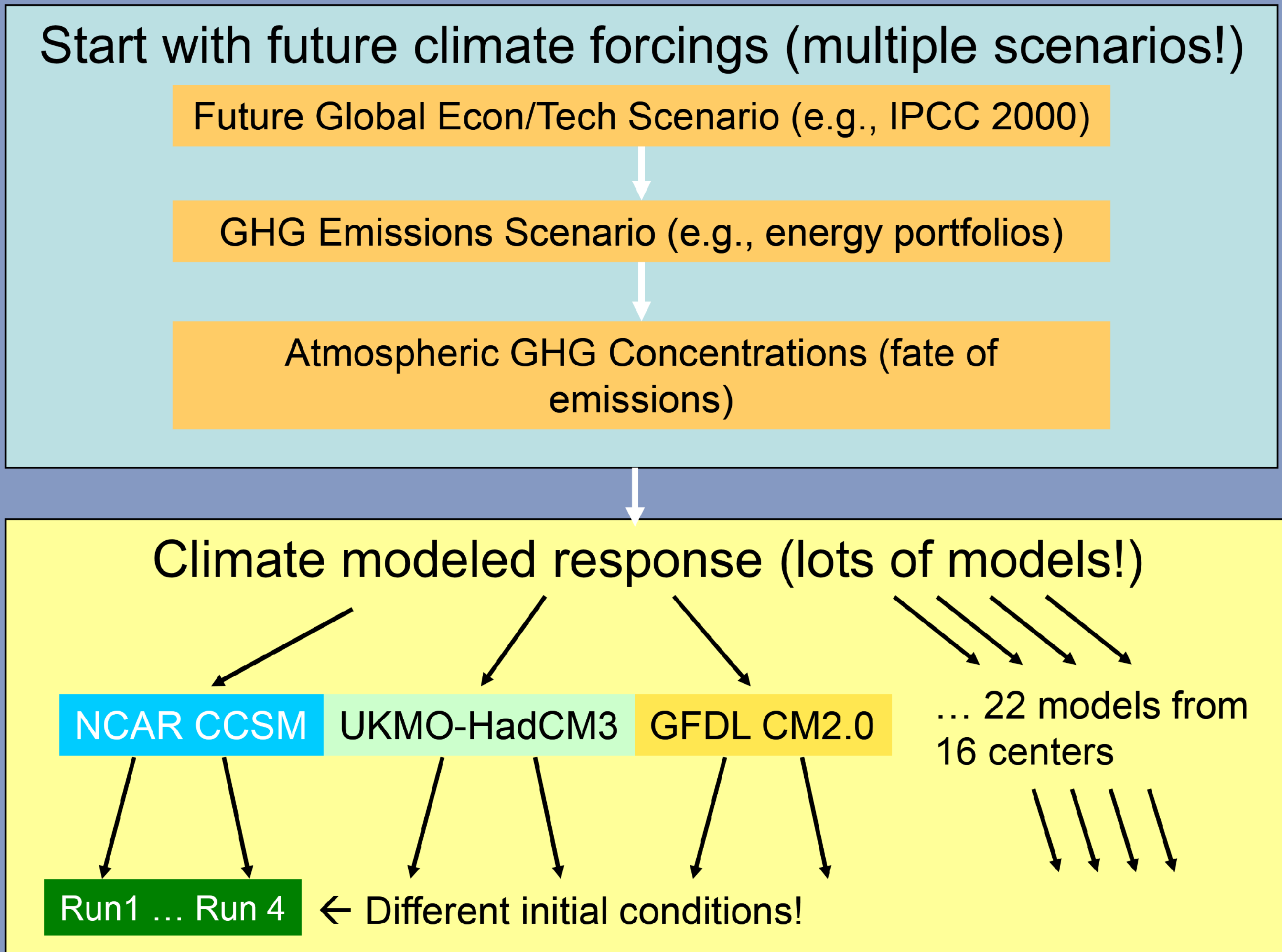
More than just a few choices



Courtesy: Barsugli

RMJOC

What subsets are appropriate for planning purposes? Which data type is best for each planning study?

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20 Climate Projections

10 Global Climate Models **x** A1b and B1 emission scenarios

x sampled changes from 1971-2000 to either… 2010-2039 / 2040-2069

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RMJOC

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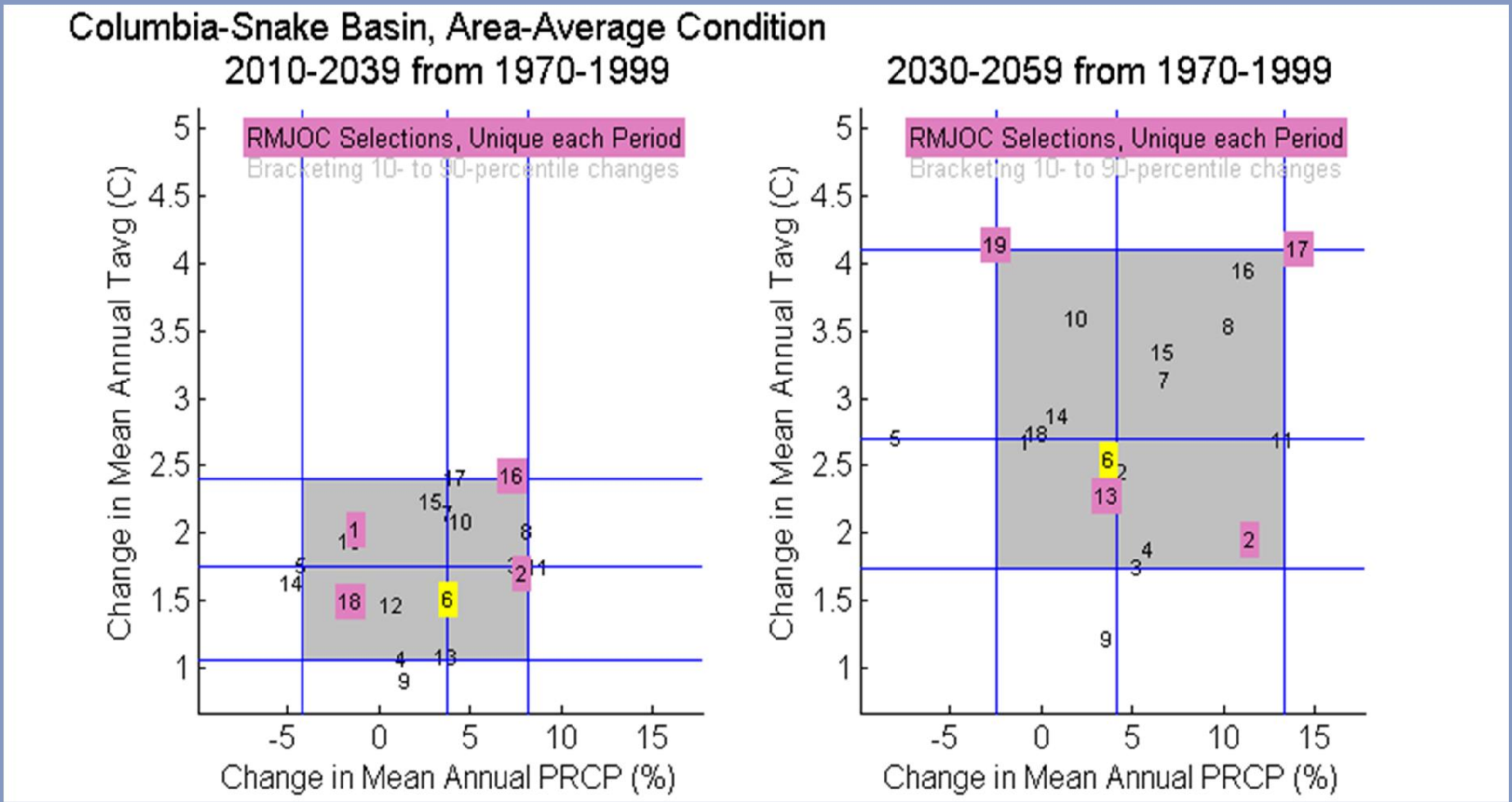
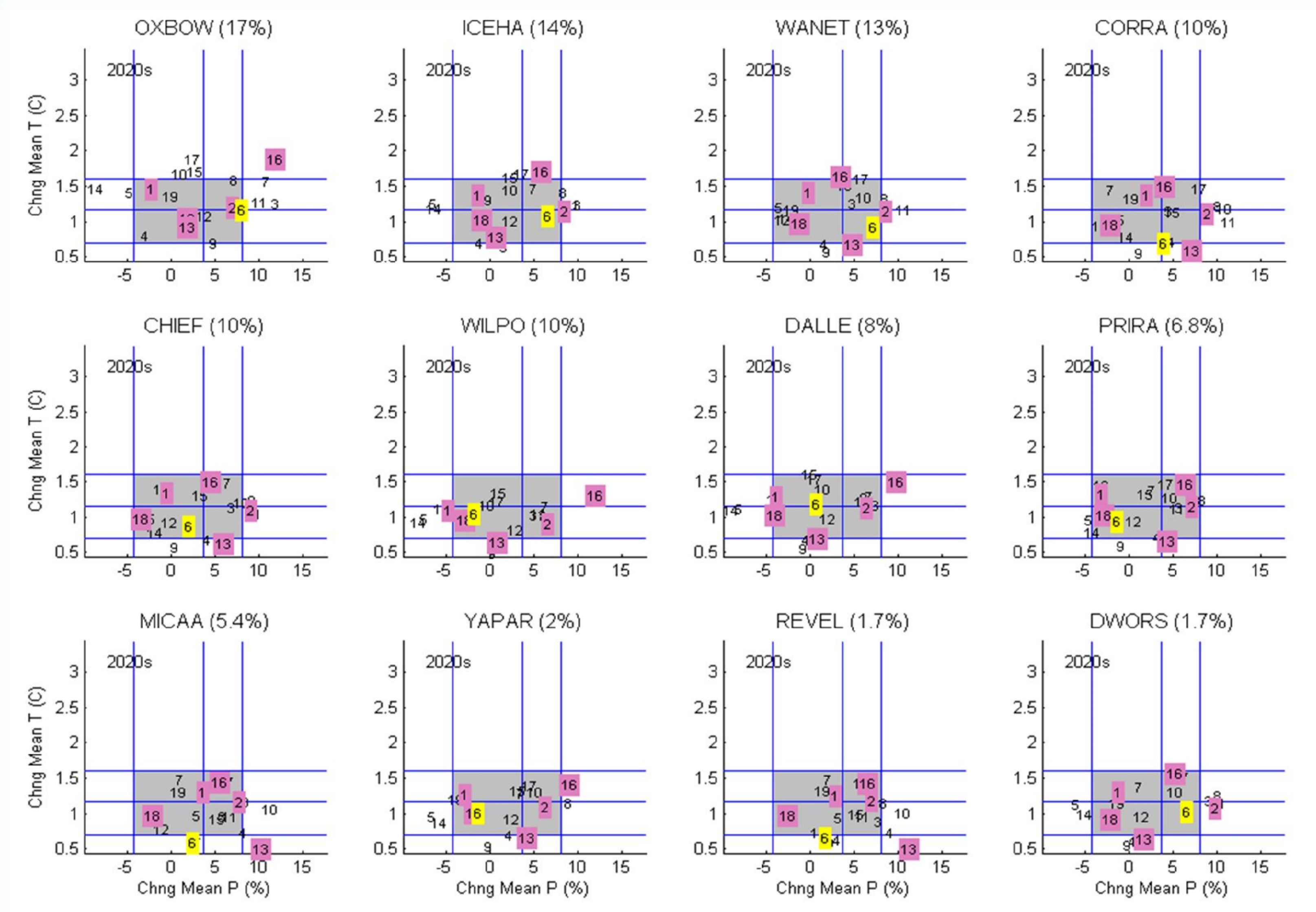


Selected Scenarios: Sub-basins

RMJOC



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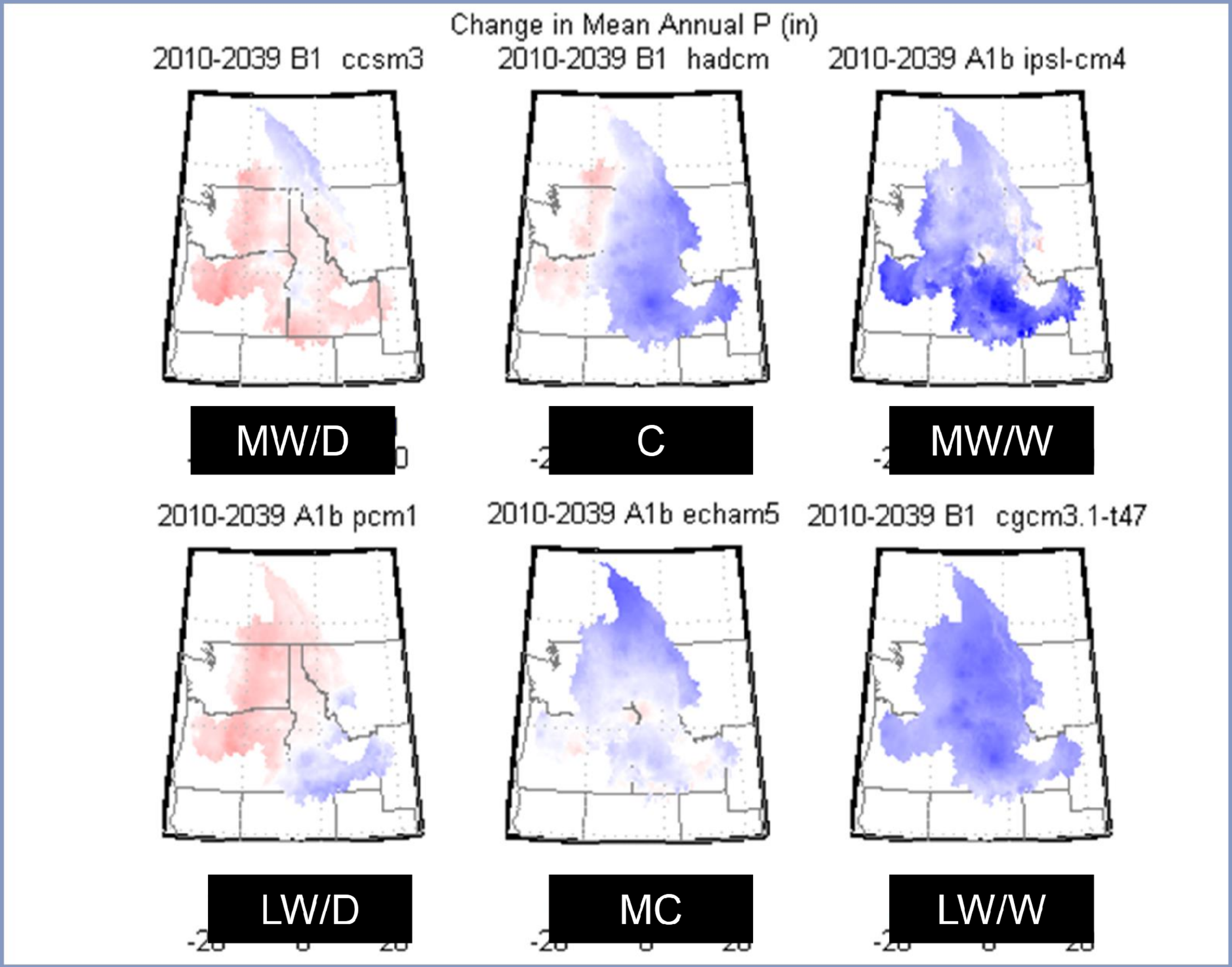
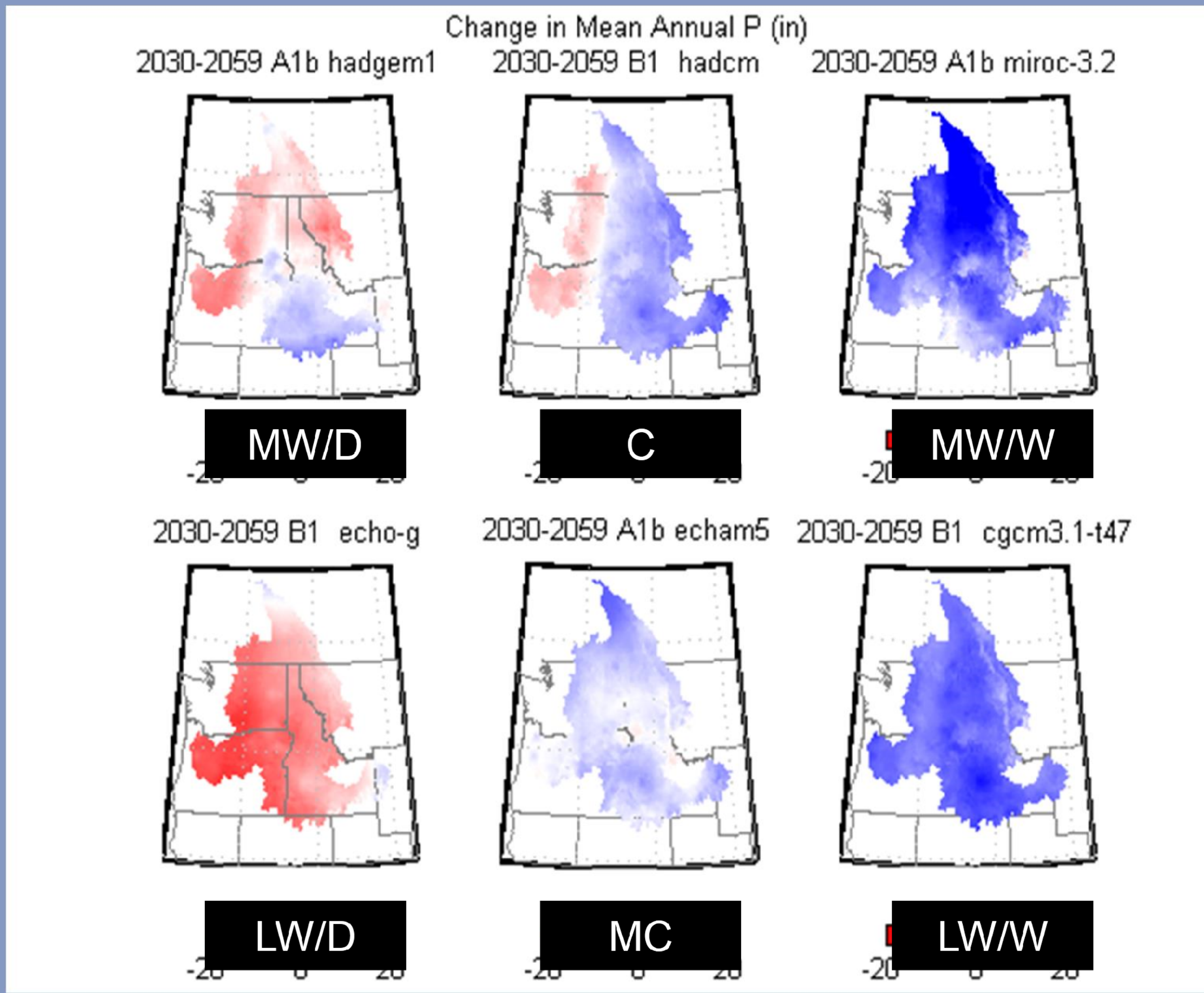
RMJOC



Precipitation:
Selected HD **2020s** Scenarios

RMJOC



Precipitation: Selected HD **2040s** Scenarios

RMJOC

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3.4 Reservoir operations modeling	Prepping and waiting on 3.3

RMJOC

Current Activities

- Water Supply Forecasts
  - Creating "synthetic" volume forecasts to reflect climate altered conditions at the time of forecast (snowpack, precipitation, runoff)
- Rules Curves
  - Using synthetic volume forecasts, compute synthetic rule curves (flood control, variable energy refill curves)
- Hydro-regulation Modeling
  - Hydsim (BPA)

FCRPS

RMJOC

Possible Applications in Next 1-3 Years

- 2014/2024 Columbia River Treaty Review
- NEPA
- Bi-Op Studies
- Flood Risk Management (Corps)
- NPCC Power Plan

RMJOC

Questions?

RMJOC

RMJOC Climate and Hydrology Dataset for use in Agencies' Longer-Term Planning Studies

Nancy Stephan
Bonneville Power Administration
VP Strategy Meeting
May 17, 2010
Portland Oregon

RMJOC

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RMJOC

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3. Use only a subset of both data sets

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RMJOC

CIG Study Partnerships

Funding Partners:

WA Department of Ecology (via HB 2860)
Bonneville Power Administration
Northwest Power and Conservation Council
Oregon Water Resources Department
BC Ministry of the Environment

Collaborative Partners:

Montana Department of Natural Resources
Idaho Department of Water Resources
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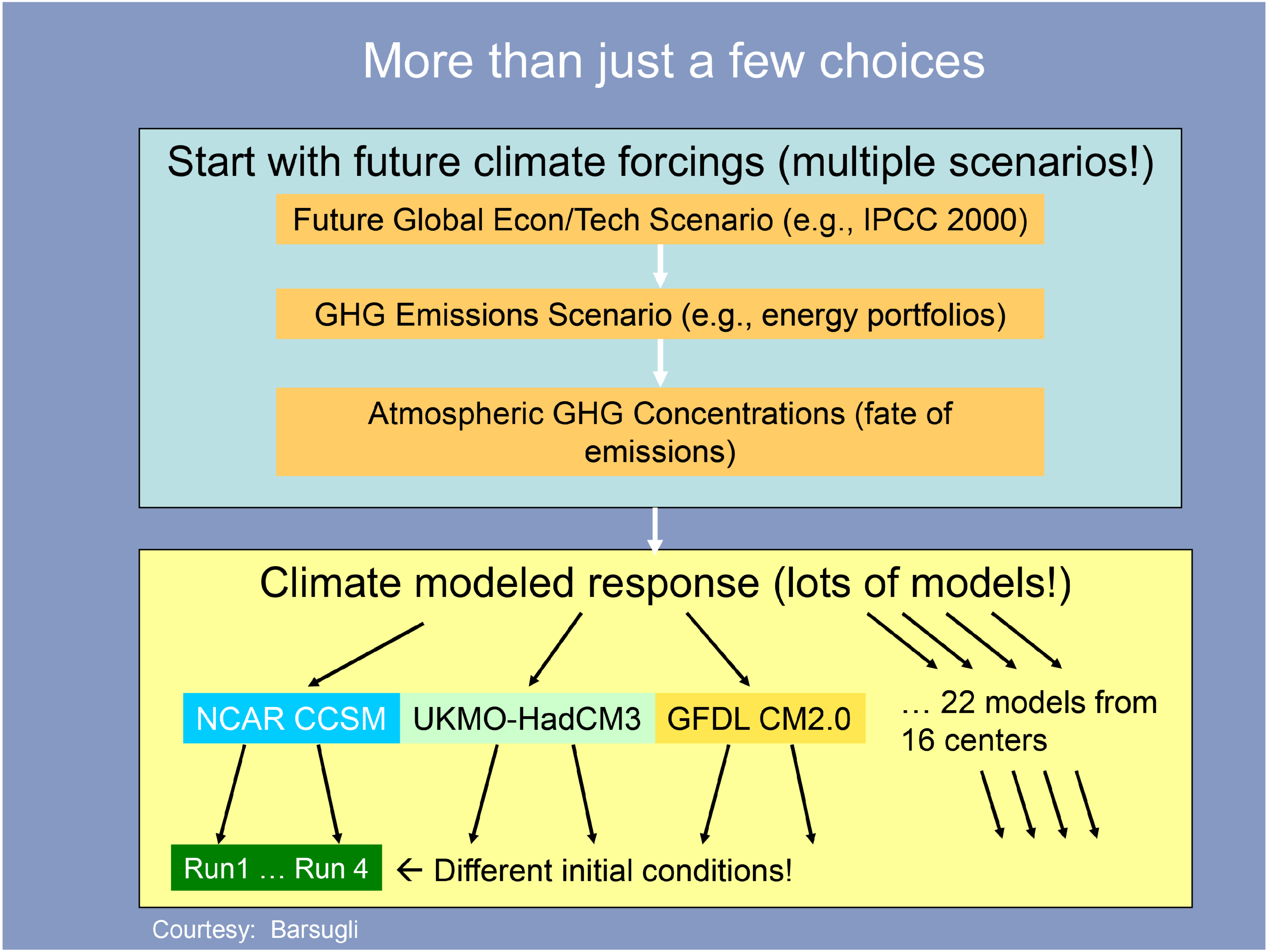
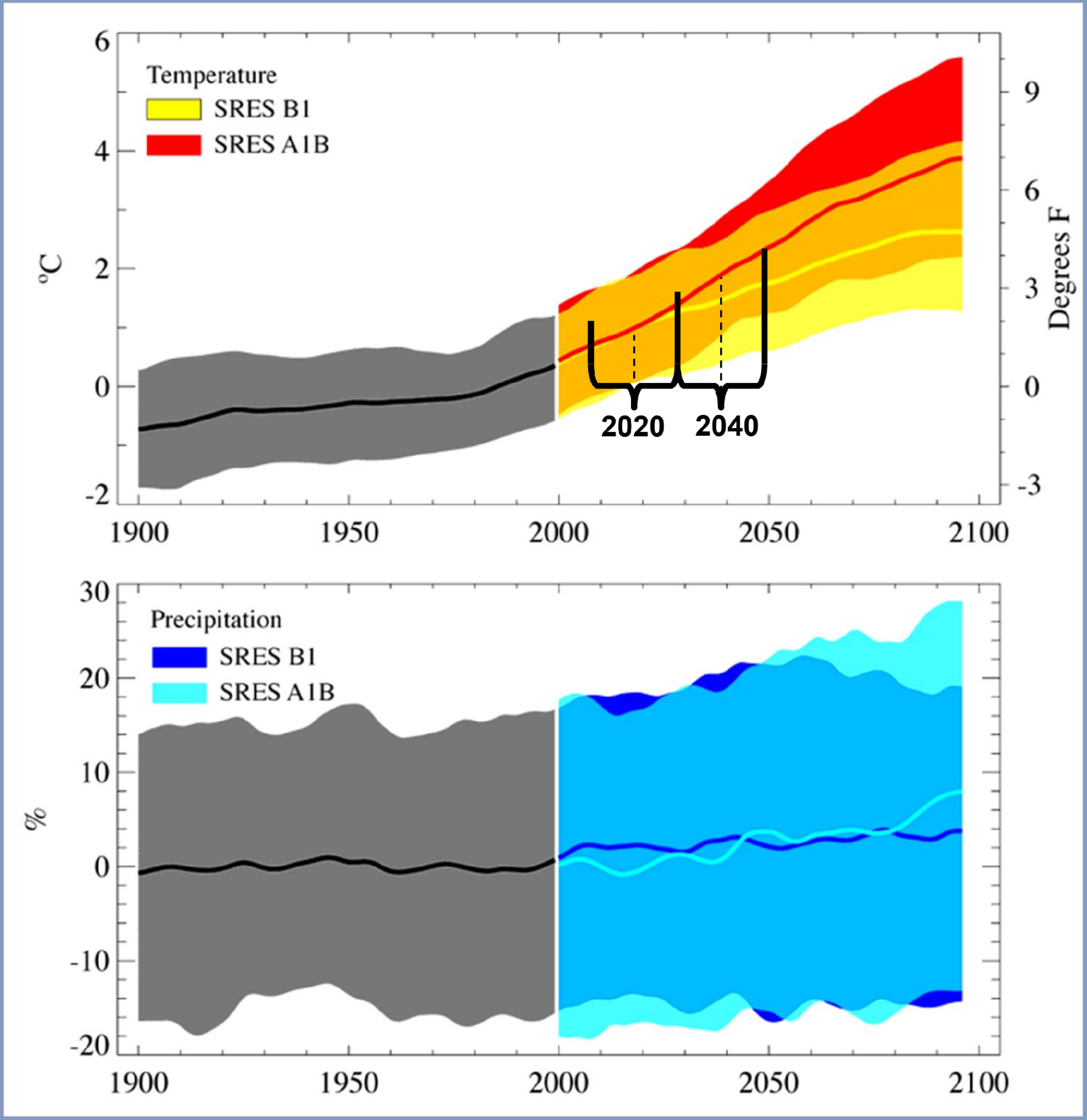

More than just a few choices
Start with future climate forcings (multiple scenarios!)
Future Global Econ/Tech Scenario (e.g., IPCC 2000)
GHG Emissions Scenario (e.g., energy portfolios)
Atmospheric GHG Concentrations (fate of emissions)
Climate modeled response (lots of models!)
NCAR CCSM
UKMO-HadCM3
GFDL CM2.0
… 22 models from 16 centers
Run1 … Run 4
← Different initial conditions!
Courtesy: Barsugli

RMJOC



Future Climate in the Northwest: Philip W. Mote and Eric P. Salathé Jr.

RMJOC

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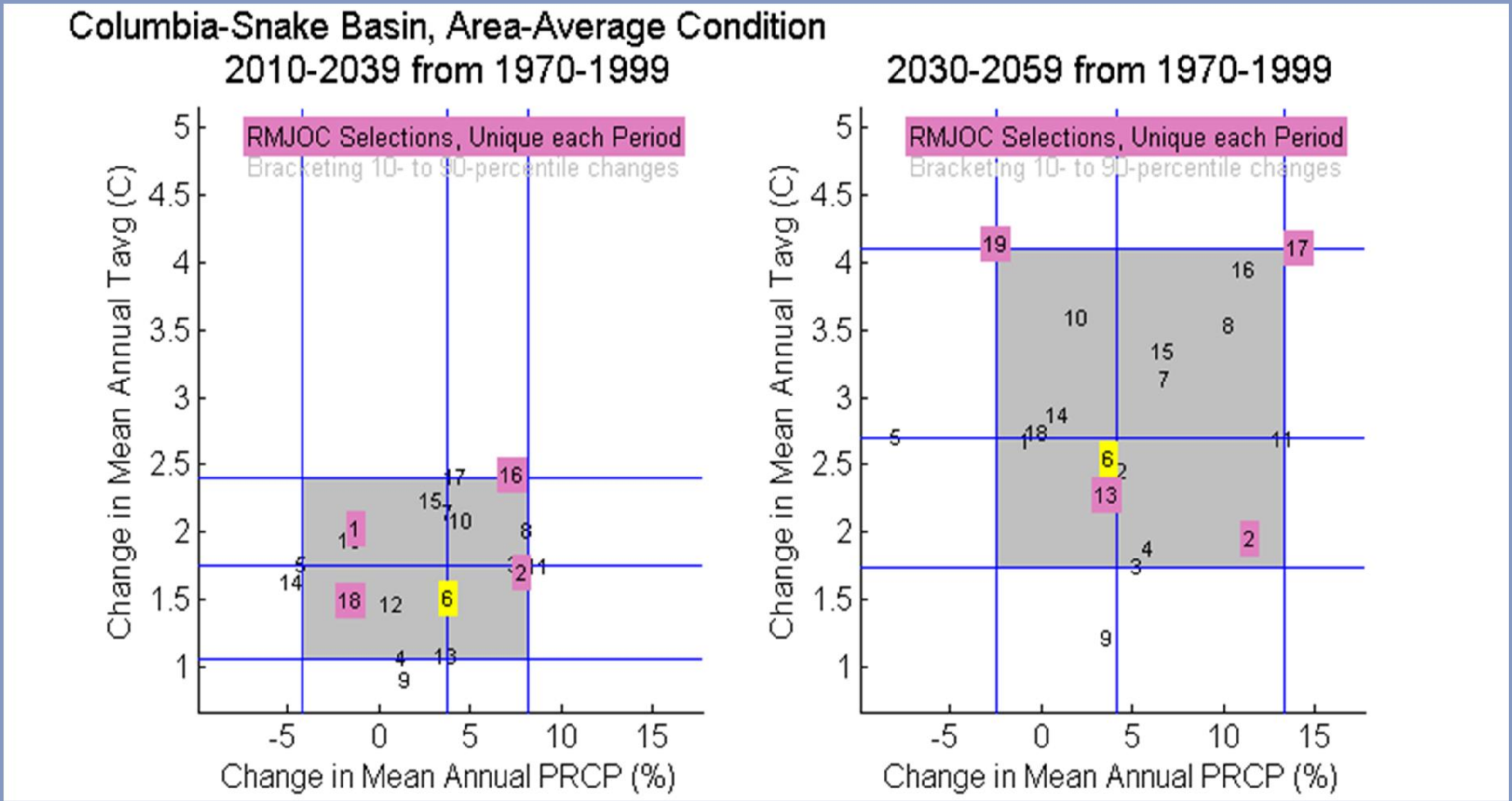
- Unique to each period?
- Based on which inflow points?



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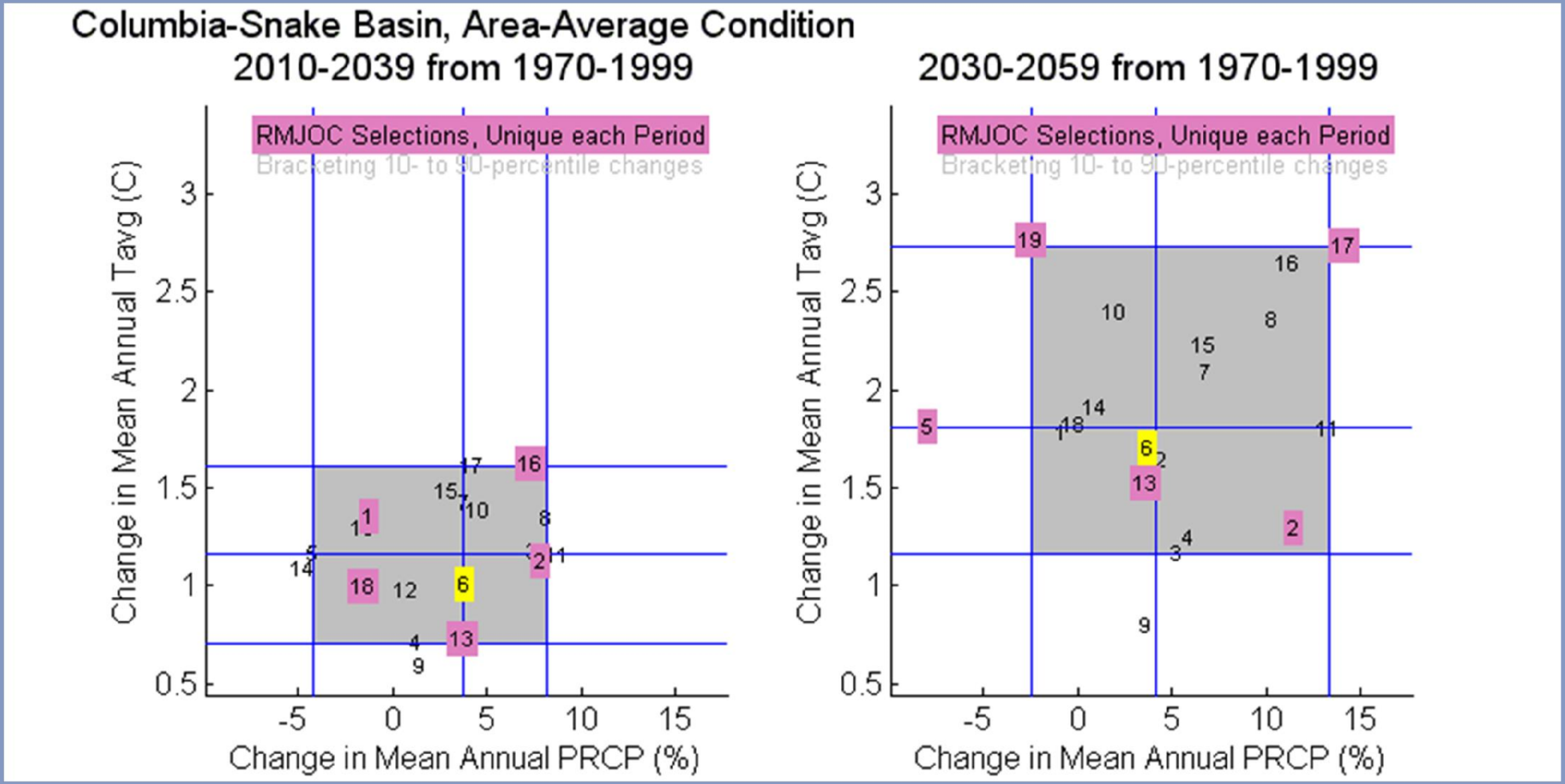
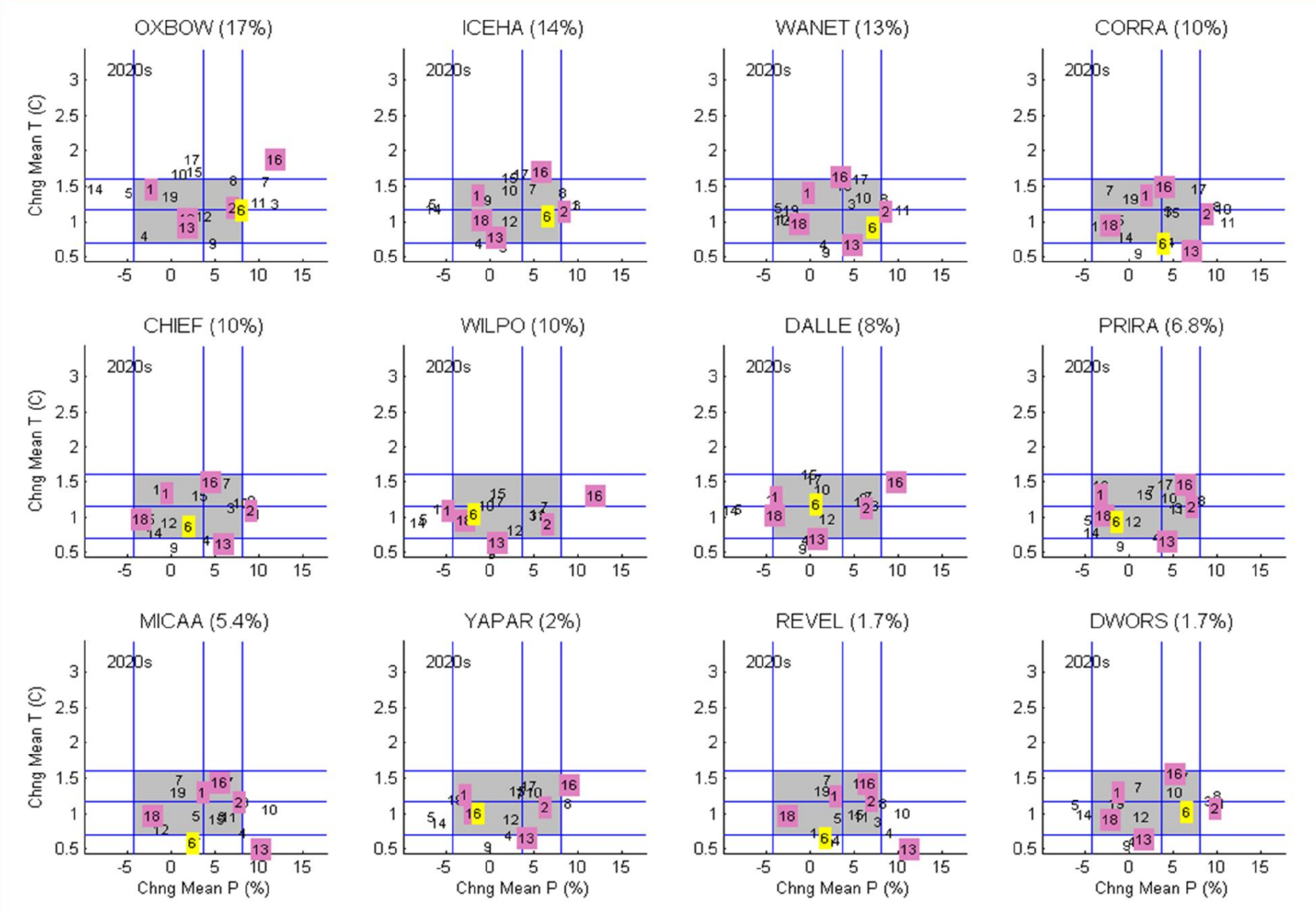
Selected Scenarios: The Dalles



Selected Scenarios: Sub-basins



Summary of Projections Selected

				Hybrid Selections						
				2020s			2040s			
Number		GCM [2]	Emissions Scenario	Selected (Labels) [3]	Change in P (in) [4]	Change in T (°C)	Selected (Labels)	Change in P (in)	Change in T (°C)	Transient (x = selected, o = not selected)
1	√	ccsm3	B1	MW/D	-1.2	1.4		-0.8	1.8	x
2	√	cgcm3.1 t47	B1	LW/W	7.9	1.1	LW/W	11.5	1.3	x
3		cnrm cm3	B1		7.5	1.2		5.3	1.2	o
4		echam5	B1		1.3	0.7		5.9	1.2	o
5	√	echo g	B1		-4.2	1.2	LW/D	-7.9	1.8	x
6	√	hadcm	B1	C	3.8	1.0	C	3.7	1.7	x
7		ipsl cm4	B1		3.8	1.4		6.9	2.1	
8		miroc 3.2	B1		8.1	1.3		10.4	2.3	
9		pcm1	B1		1.5	0.6		3.6	0.8	o
10		ccsm3	A1b		4.6	1.4		2.0	2.4	o
11		cgcm3.1 t47	A1b		8.8	1.2		13.4	1.8	o
12		cnrm cm3	A1b		0.8	1.0		4.1	1.6	o
13	√	echam5	A1b	MC	3.7	0.7	MC	3.7	1.5	x
14		echo g	A1b		-4.7	1.1		0.9	1.9	o
15		hadcm	A1b		3.0	1.5		6.7	2.2	o
16	√	ipsl cm4	A1b	MW/W	7.4	1.6		11.2	2.6	
17	√	miroc 3.2	A1b		4.2	1.6	MW/W	14.2	2.7	
18	√	pcm1	A1b	LW/D	-1.5	1.0		-0.2	1.8	x
19 [1]	√	hadgem1	A1b		-1.5	1.3	MW/D	-2.5	2.8	

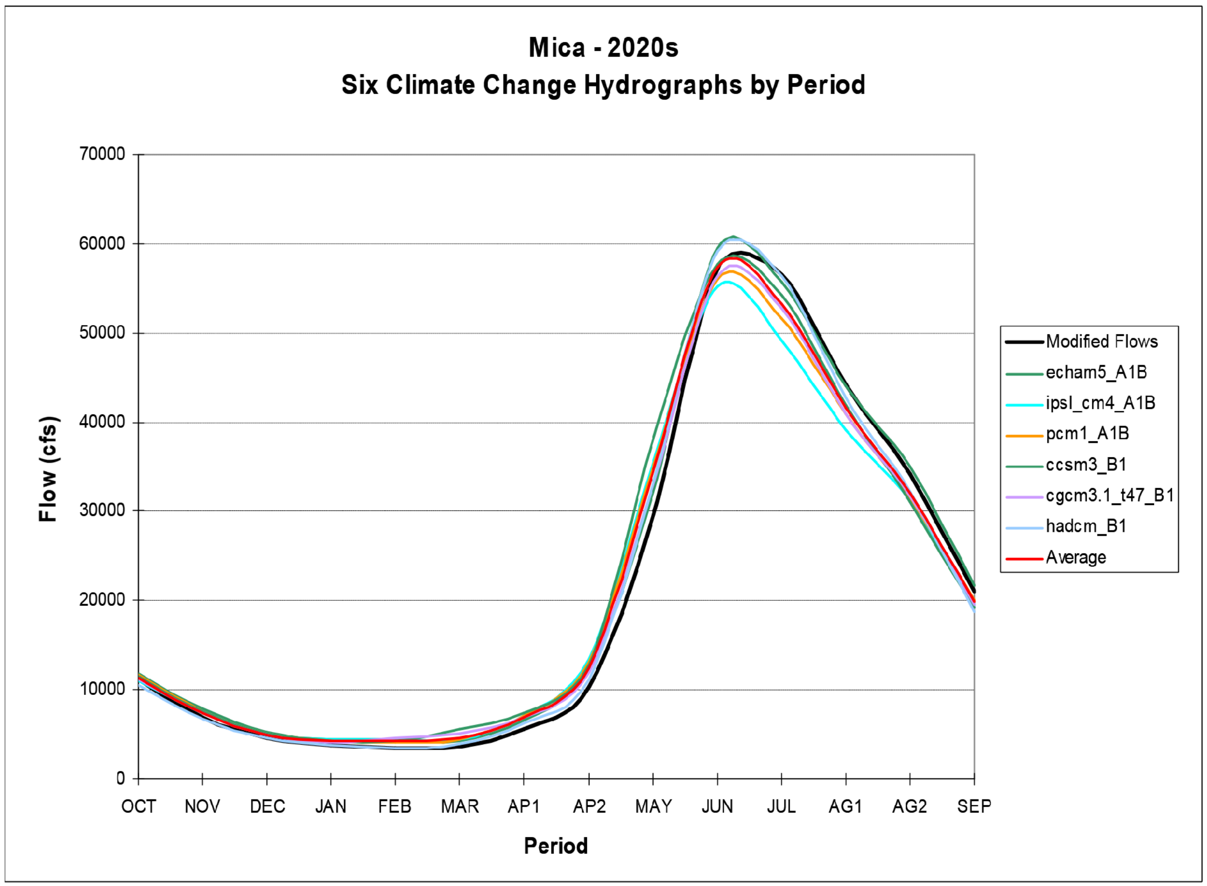
Notes

[1] Number 19 was not included in Oct 24 workbook shared with stakeholders.

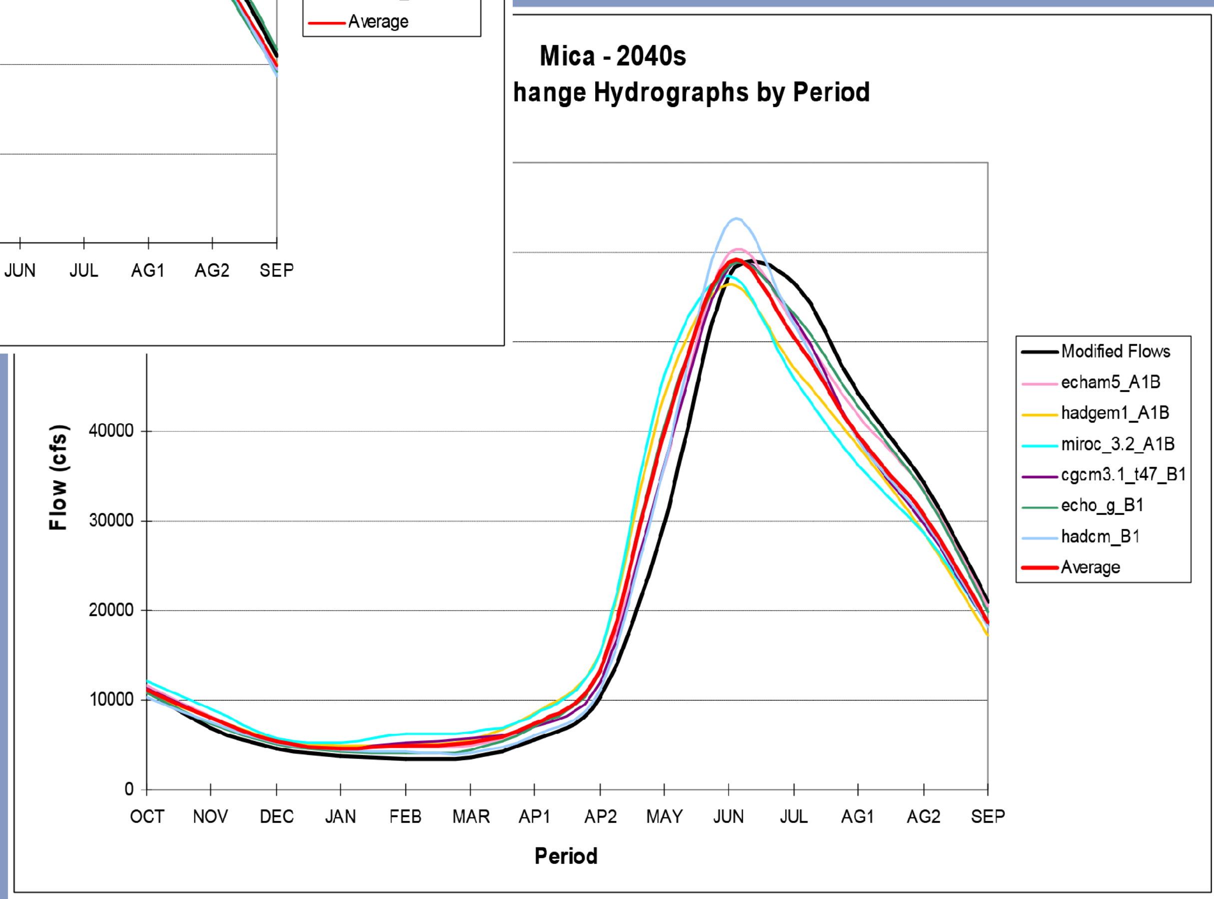
[2] Green shaded GCMs are those that BC Hydro suggested as being part of a "better set of GCMs." (Dec 2, Frank Weber email)

[3] Selected Labels: MW = More Warming, LW = Less Warming, W = Wetter, D = Drier, MC = Minor Change, C = Central Change

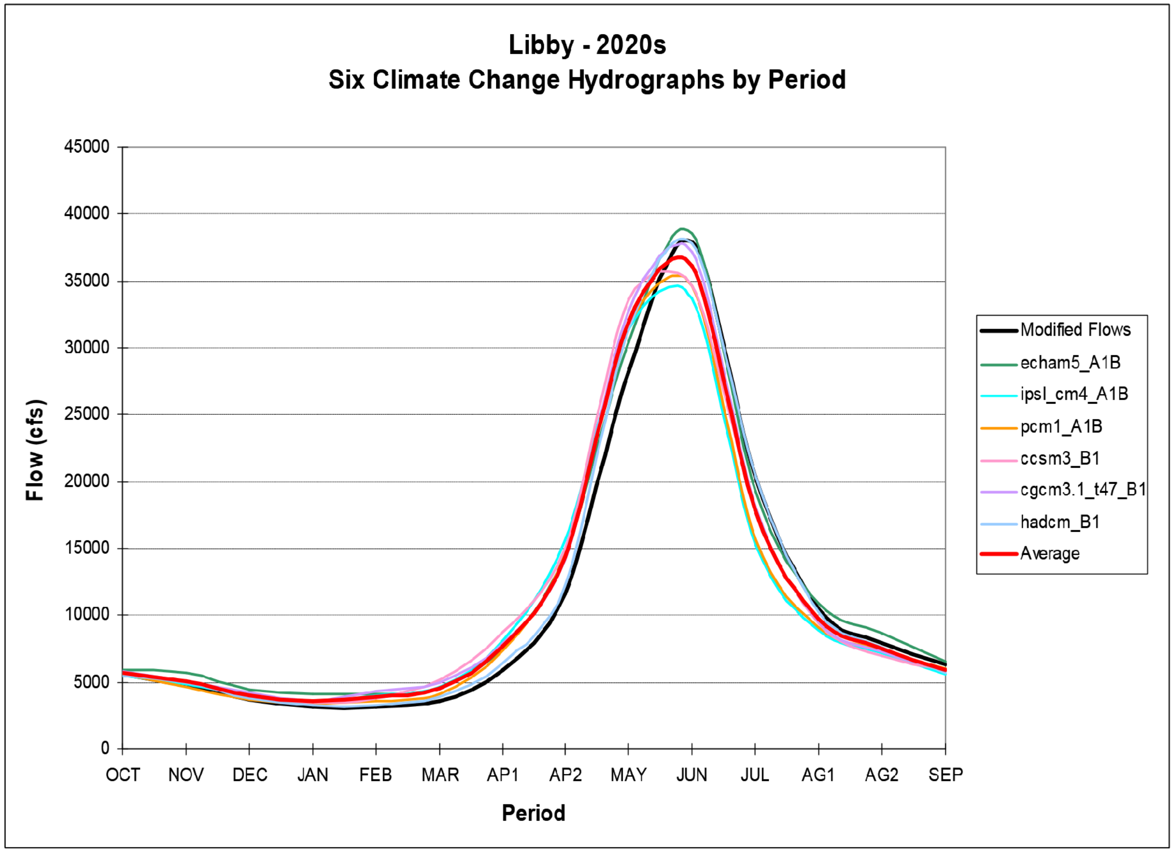
[4] P = precipitation, T = average daily temperature, "Change in" means change in 92-year period-mean annual condition. For assessing change, the reference is Observed Climate Variability, 1916-2006. The changed condition is the 92-year Observed Climate Variability sequence adjusted to match climate characteristics of a projected 30-year period (2020s = 2010-2039 and 2040s = 2030-2059) from the given underlying climate projection (column Number).

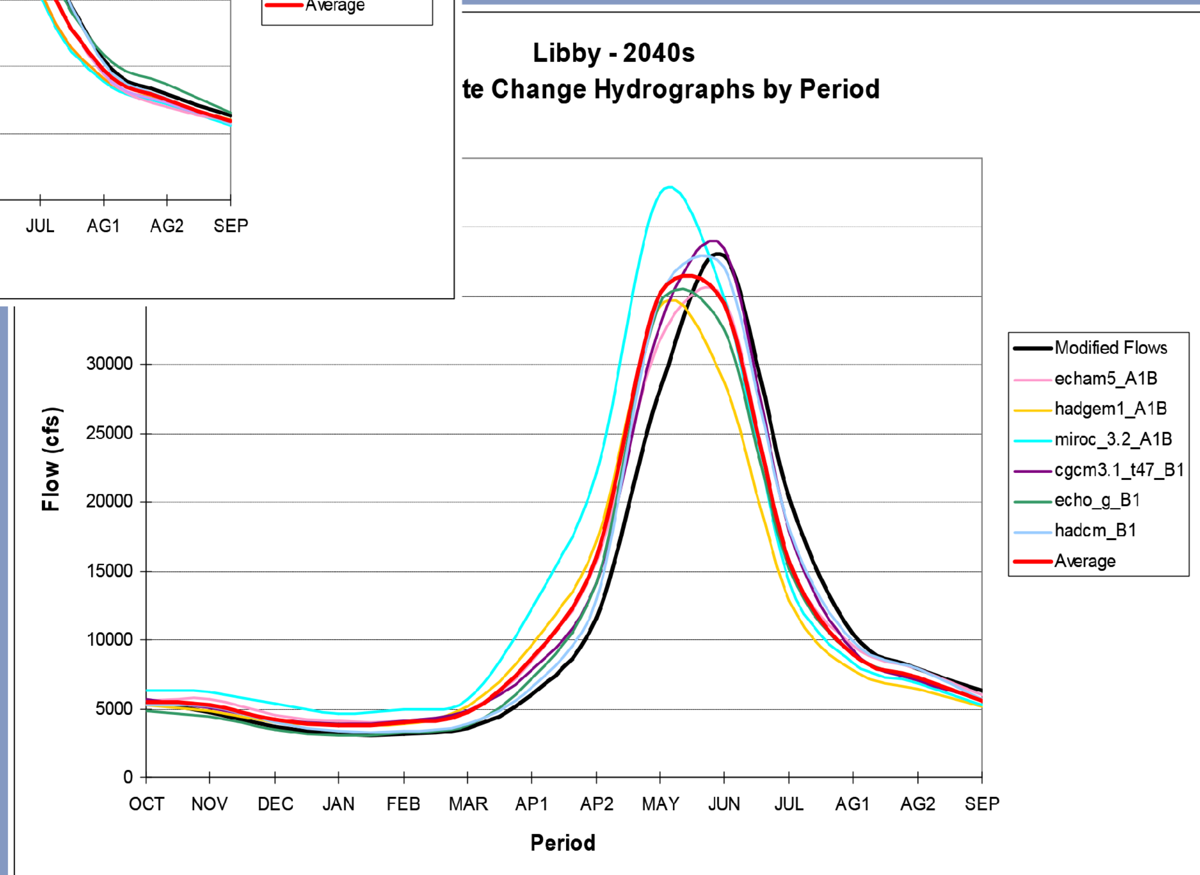


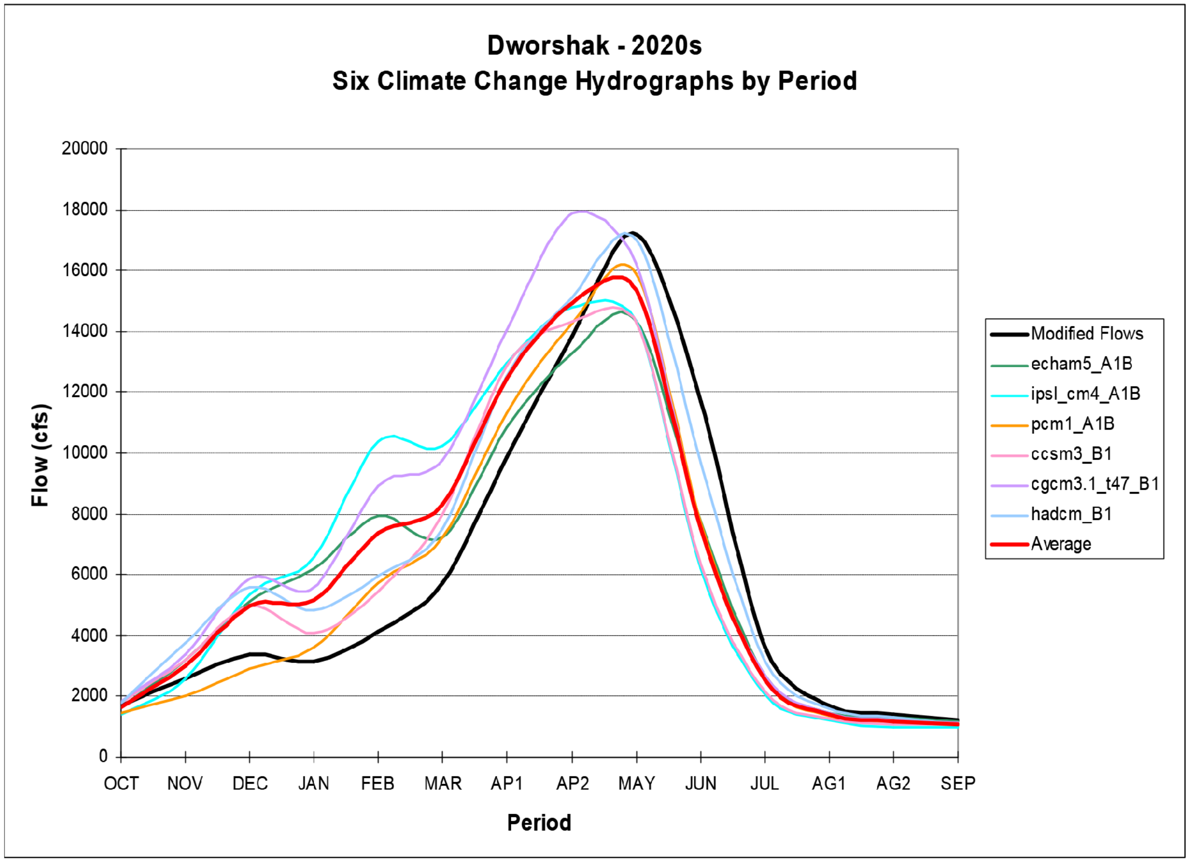
Mica - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
70000
60000
50000
40000
30000
20000
10000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average

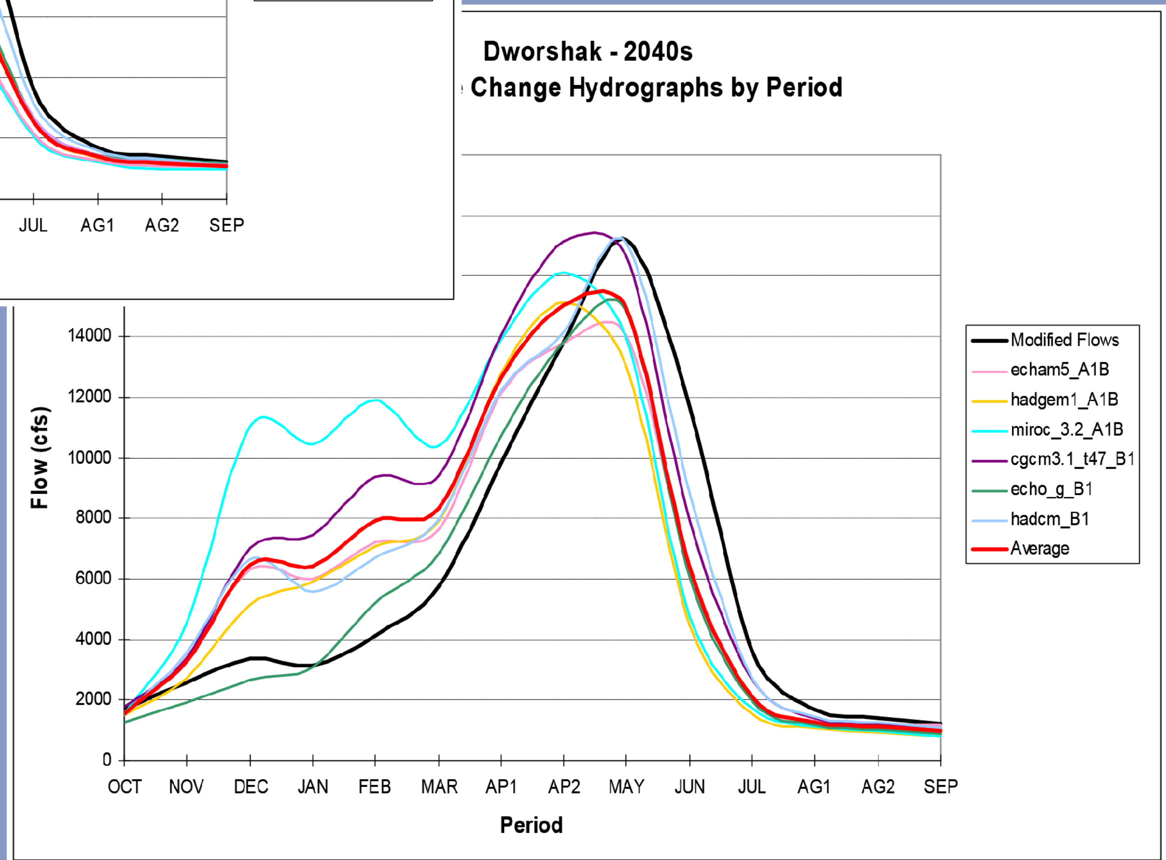


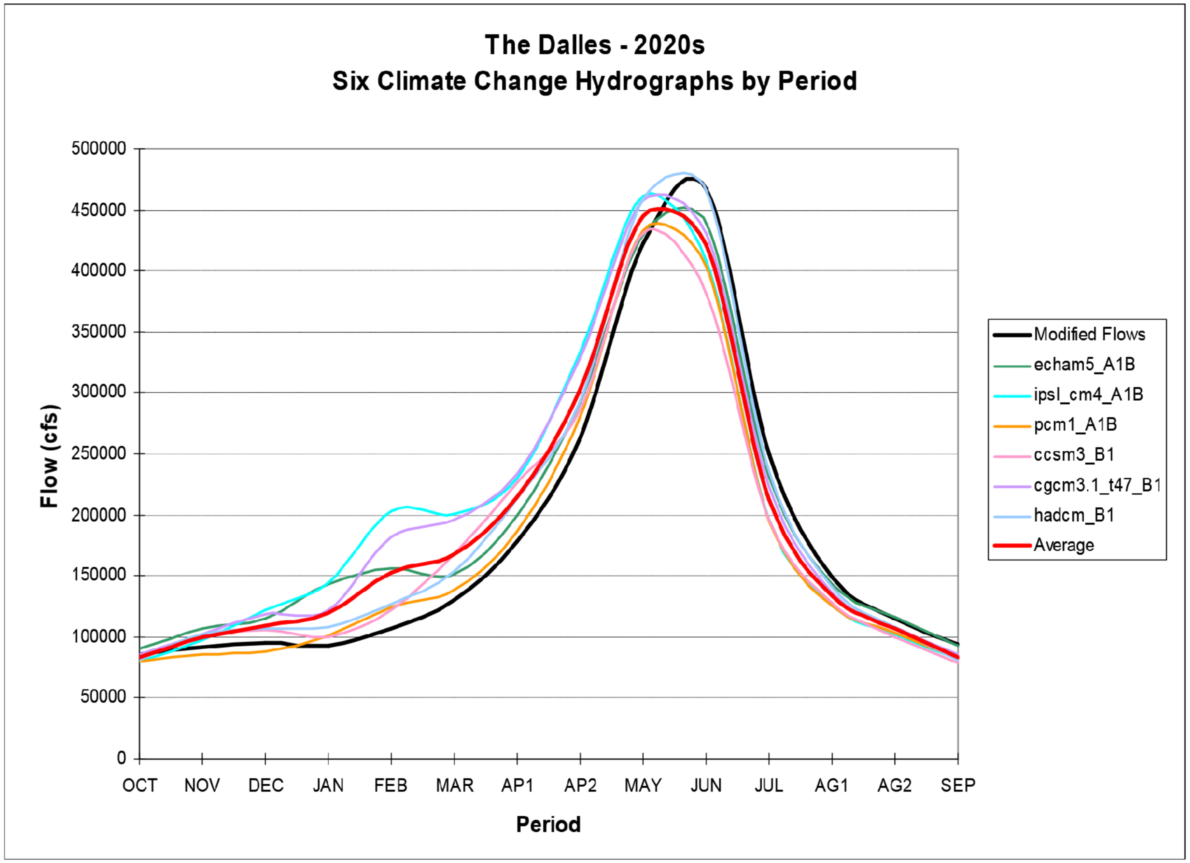
Mica - 2040s
hange Hydrographs by Period
Flow (cfs)
40000
30000
20000
10000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average

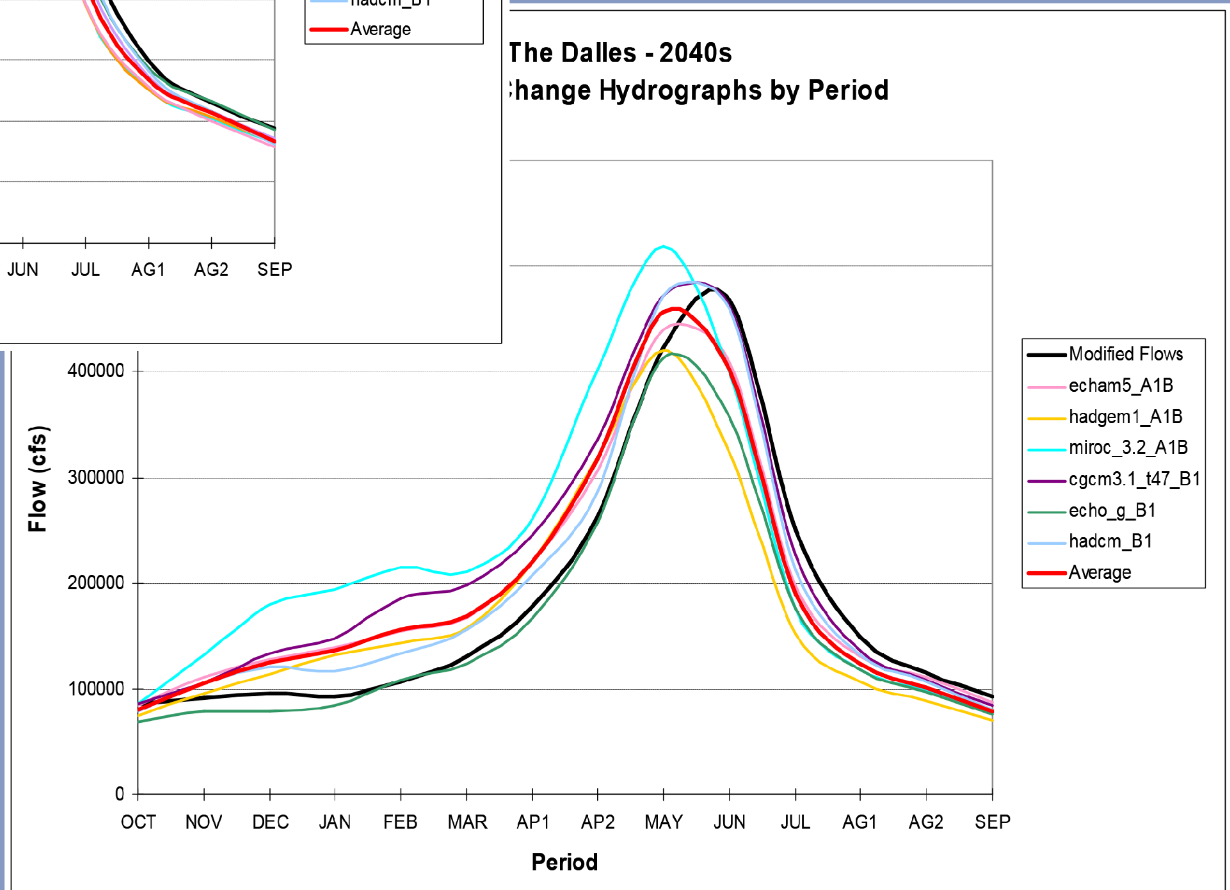

Libby - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
OCT NOV DEC JAN FEB MAR AP1 AP2 MAY JUN JUL AG1 AG2 SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average


Libby - 2040s
te Change Hydrographs by Period
Flow (cfs)
30000
25000
20000
15000
10000
5000
0
OCT NOV DEC JAN FEB MAR AP1 AP2 MAY JUN JUL AG1 AG2 SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average


Dworshak - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average


Dworshak - 2040s
Change Hydrographs by Period
Flow (cfs)
14000
12000
10000
8000
6000
4000
2000
0
OCT
NOV
DEC
JAN
FEB
MAR
AP1
AP2
MAY
JUN
JUL
AG1
AG2
SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average


The Dalles - 2020s
Six Climate Change Hydrographs by Period
Flow (cfs)
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
OCT NOV DEC JAN FEB MAR AP1 AP2 MAY JUN JUL AG1 AG2 SEP
Period
Modified Flows
echam5_A1B
ipsl_cm4_A1B
pcm1_A1B
ccsm3_B1
cgcm3.1_t47_B1
hadcm_B1
Average


The Dalles - 2040s
hange Hydrographs by Period
Flow (cfs)
400000
300000
200000
100000
0
OCT NOV DEC JAN FEB MAR AP1 AP2 MAY JUN JUL AG1 AG2 SEP
Period
Modified Flows
echam5_A1B
hadgem1_A1B
miroc_3.2_A1B
cgcm3.1_t47_B1
echo_g_B1
hadcm_B1
Average

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Project Status

TASK	STATUS
1.1 Review of Climate Projection Information from US CIG	COMPLETE
1.2 Selection of Subset	COMPLETE
1.3 Documentation and Internal Review	In progress (2/3)
2.1 Obtain/review hydrologic mode (VIC)	In progress (not on CP)
2.2 Obtain and review daily weather inputs	COMPLETE
2.3 Obtain/review simulated water balance and streamflow	Review – in progress
3.0 Bias-correct CIG data for BOR inputs	Complete
3.1 Prepare Inflows (incorporate BOR inflows)	In progress
3.2 Prepare seasonal runoff volume forecasts	Waiting on 3.1
3.3 Compute FC targets and VECC	Waiting on 3.1, 3.2
3.4 Demonstration Analyses	Prepping and waiting on 3.1, 3.2, 3.3

Synthetic Water Supply Forecasts

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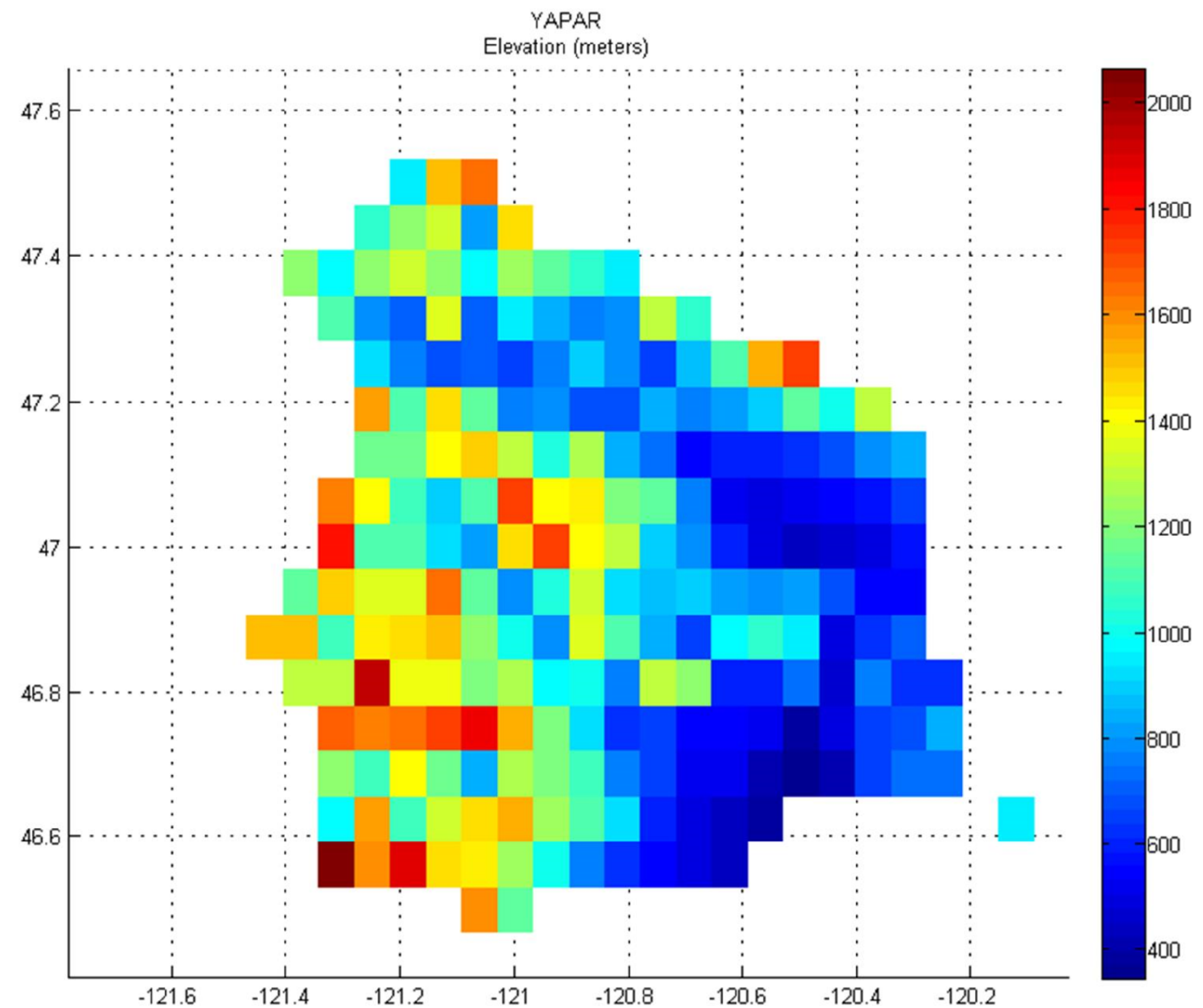

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Deliverables

(#1) Subset of UW CIG Regional Climate Projection Information

- Step-change in climate ("hybrid")
- Time-developing climate ("transient")

(#2) Daily weather inputs for hydrologic modeling (both types)

(#3) Daily hydrologic modeling results (both types)

(#4) Streamflows bias-corrected or adjusted for reservoir operations/regulation modeling

(#5) Seasonal runoff volume forecasts

(#6) Develop Flood Control and Operating Rule Curves

(#7) Demonstration Study by RMJOC agencies' staff

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Collaborative Workshops

June 9, 2009
October 16, 2009
December 7, 2009
April 19, 2010

- Corps (Districts and Division)
- BPA
- BOR
- CIG
- NWRFC
- FWS
- NOAA Fisheries
- Columbia River Inter-Tribal Fish Commission
- Northwest Power and Conservation Council
- NRCS
- BC Hydro
- OCCRI

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Applications in Next 1-3 Years

- 2014/2024 Columbia River Treaty Review
- NEPA
- Bi-Op Studies
- Flood Risk Management (Corps)
- NPCC Power Plan

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RMJOC Climate Change Initiative Sovereign Technical Team

Presented by:

Nancy Stephan – Bonneville Power Administration

May 18, 2011

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- The Joint Operating Committee (JOC) was established through the Direct Funding Memorandum of Agreements (MOAs) between BPA, Reclamation, and the Corps for the asset planning, maintenance, and operation of the FCRPS.
- The River Management Joint Operating Committee (RMJOC) is a sub-committee specifically dedicated to reviewing the practices, procedures, and processes of each Agency to identify changes that could improve the overall efficiency of the operation and management of the FCRPS projects.

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RMJOC Motive and Need

- Motive
  - consistent incorporation of climate projection information into Agencies' longer-term planning studies
- Need
  - adopt common dataset (climate and hydrology)
  - establish consensus methods for data use
  - efficiently use limited resources through coordinated development of data and methods

Emission Scenarios

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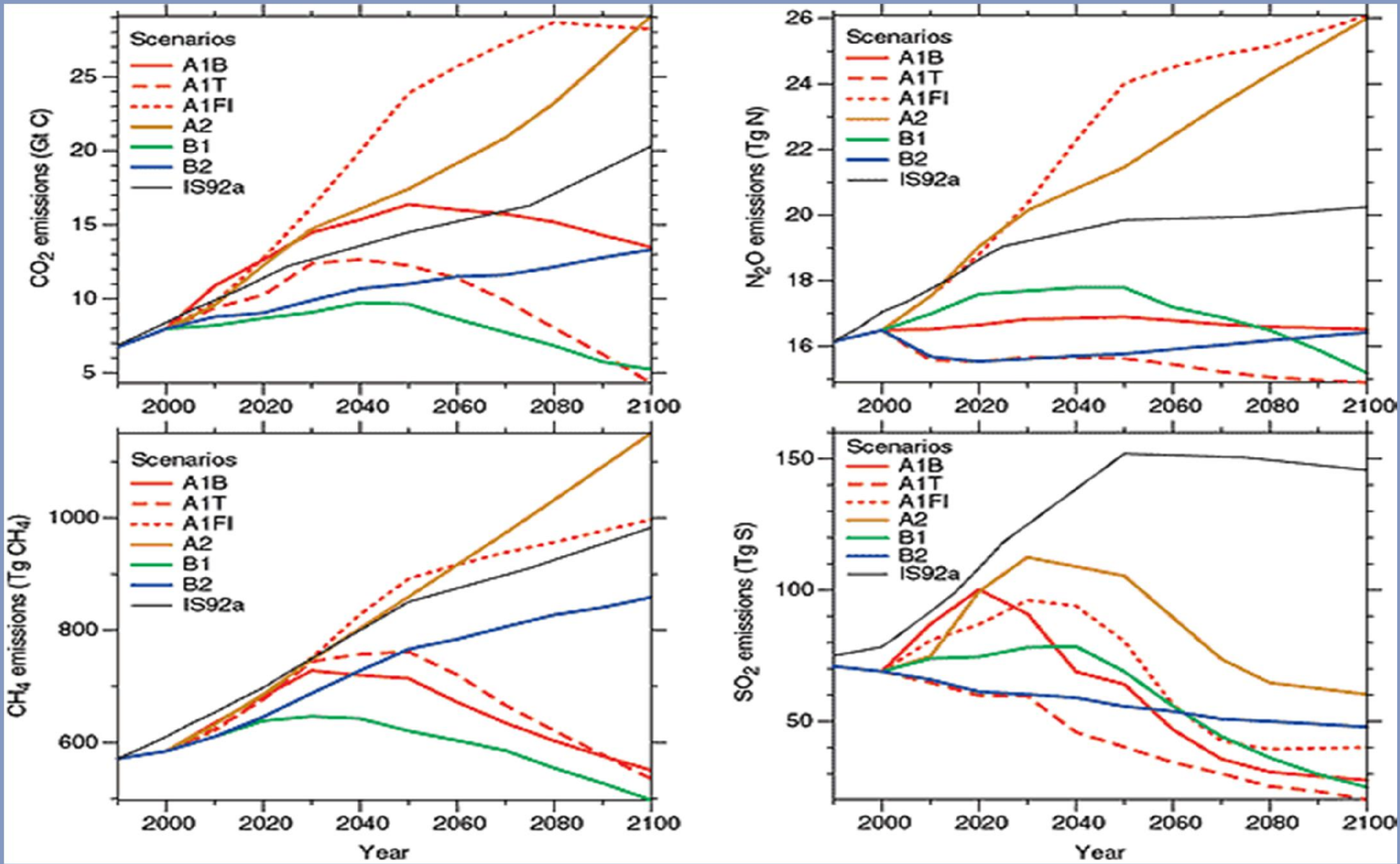

FCRPS — Federal Columbia River Power System

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Key Scoping Decisions

1. Start with existing CIG's data on regional climate and hydrology (CIG's "HB2860" regional project)

2. Use two methodologies from CIG
   - Step-change climate information (Hybrid-Delta)
   - Time-developing climate information (Transient)

3. Use only a subset of both data sets

4. Conduct modeling and analysis using both types (Hybrid-Delta and Transient)
   - Look at overall climate change impacts
   - Draw impressions on which types might be more appropriate for Agencies' longer-term planning

Original Data from CIG Effort

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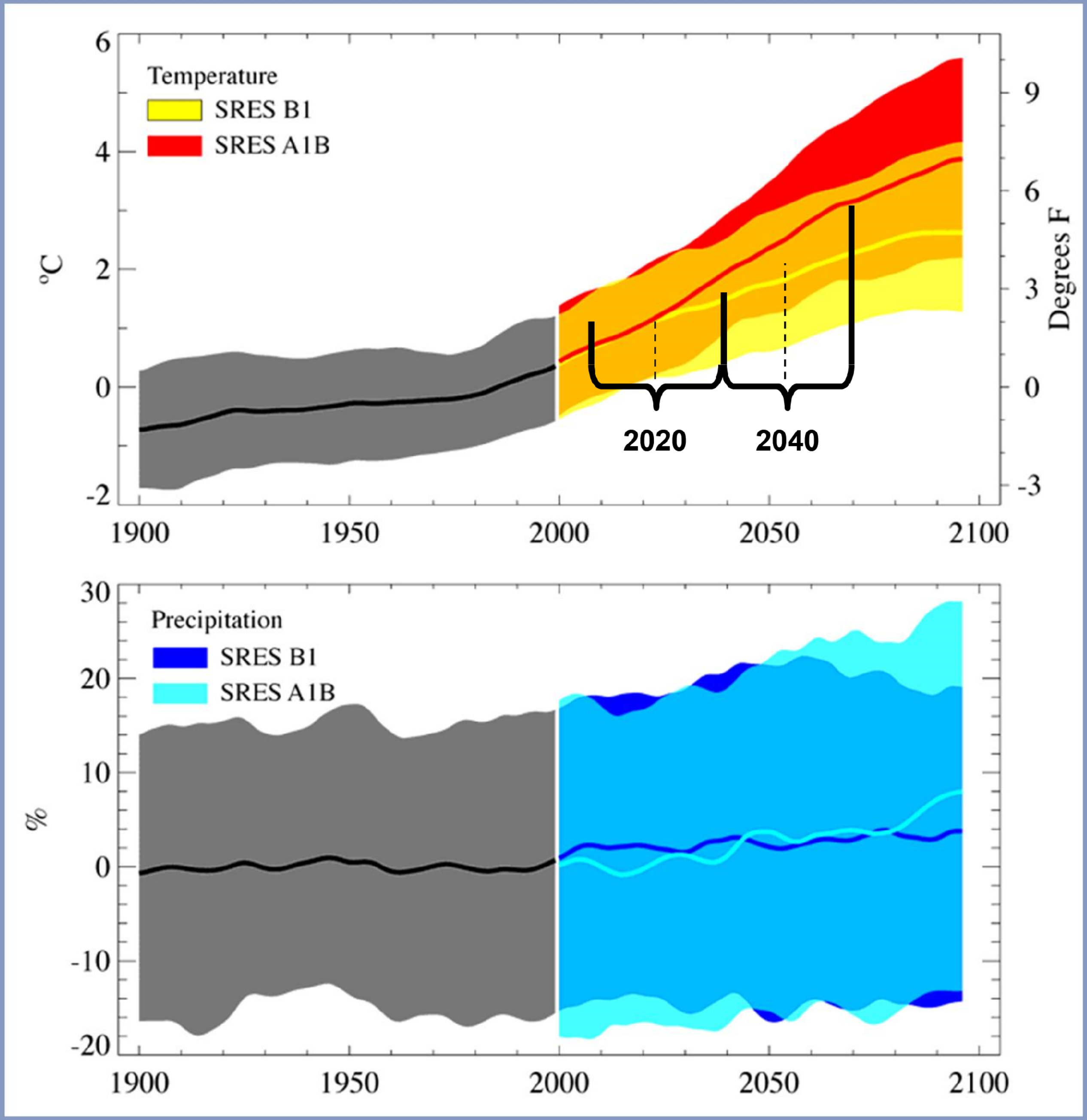
- Develop historic meteorological data at 1/16th degree (7 kilometer) from 1915- 2005
- Developed downscaled 1/16th degree meteorological data sets associated with each of 10 GCM scenarios for “2020s” “2040s” “2080s” time periods
- Run the 1/16th degree VIC hydrologic model for each of 10 GCM scenarios for the three time periods, and produce streamflow scenarios for over 200 inflow locations
- Bias adjust VIC flows to estimated monthly Modified Flows for all Hydsim and Genesys sites



Future Climate in the Northwest: Philip W. Mote and Eric P. Salathé Jr.

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What subsets are appropriate for planning purposes? Which data type is best for each planning study?

"*Hybrid-Delta*" or step-change data ("climate change")

20 Climate Projections

10 Global Climate Models X A1b and B1 emission scenarios

X sampled changes from 1971-2000 to either… 2010-2039 2040-2069

= 40"climate change" hydrologic scenarios, each 91 years in duration, having variability as observed from 1915-2005

"*Transient*" or time-developing

10 Climate Projections

7 Global Climate Models X A1b and B1 emission scenarios

= 14 hydrologic "projections", continuous from historical to future (1950-2099), having Global Climate Model variability

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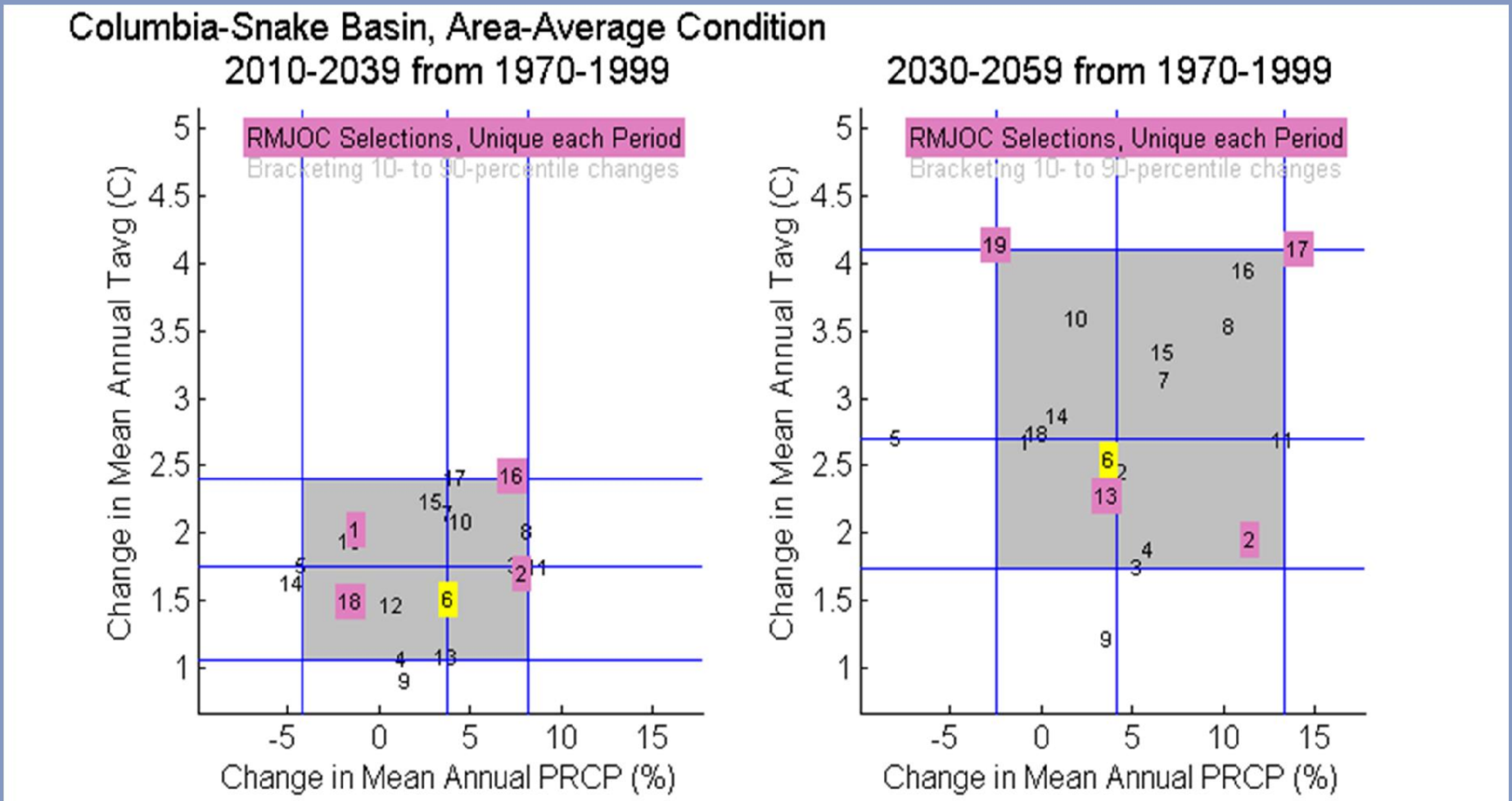
How to select the scenarios…

- 10 and 90 percentile brackets?
- 25 and 75 percentile brackets?
- Unique to each period?
- Based on which inflow points?



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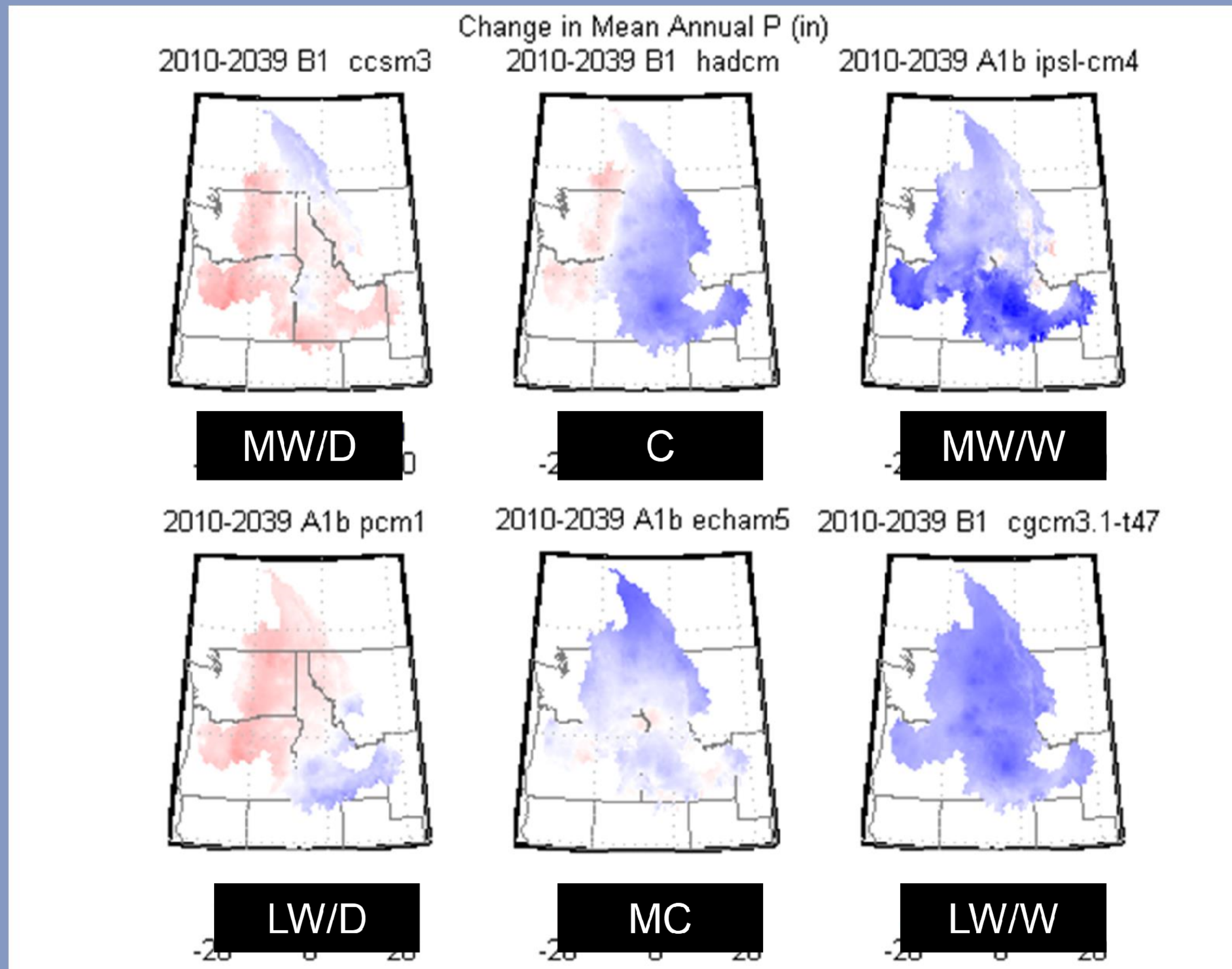
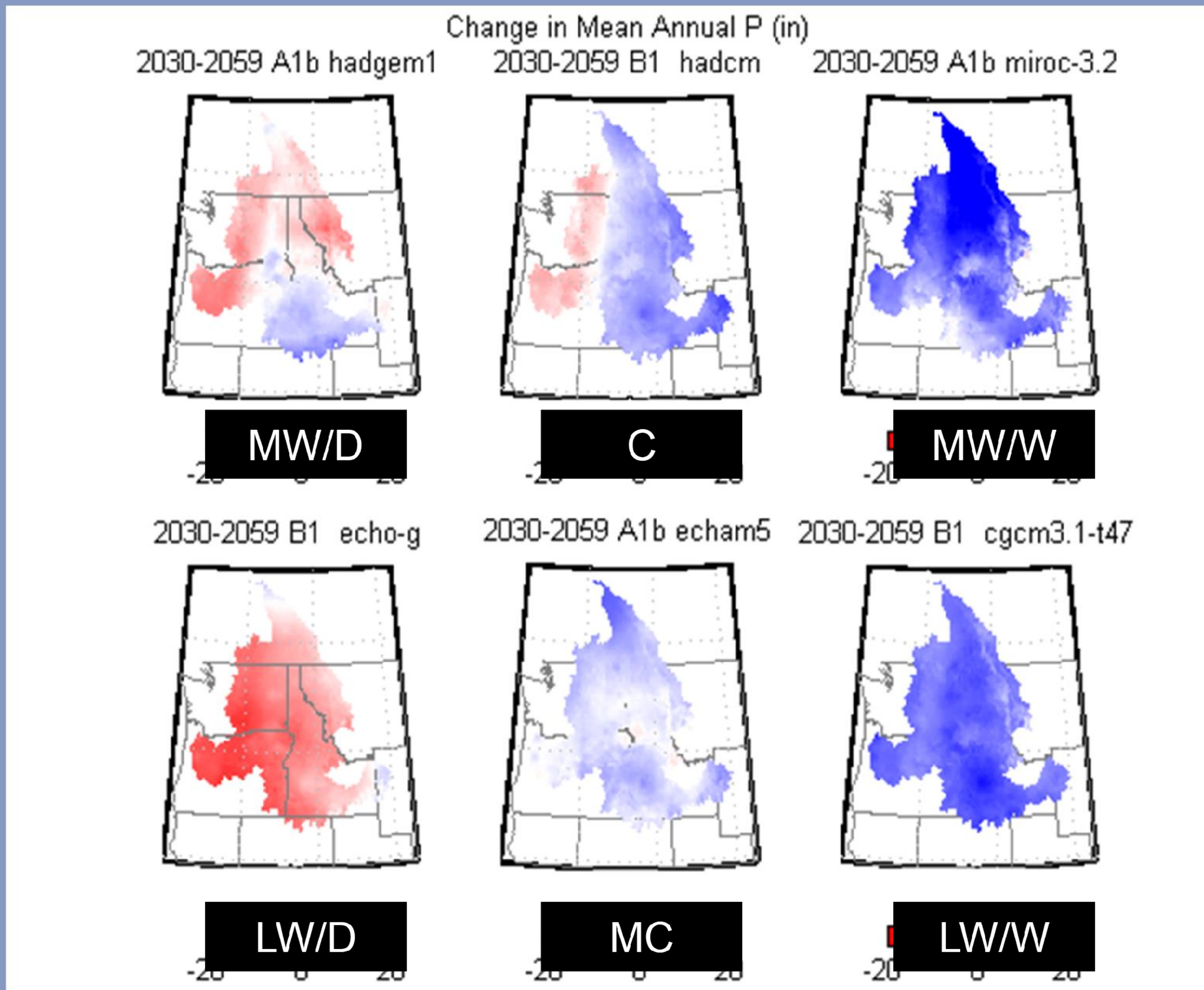


Precipitation: Selected HD **2020s** Scenarios



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Precipitation:
Selected HD **2040s** Scenarios

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Additional Development

- Water Supply Forecasts
  - Created “synthetic” volume forecasts to reflect climate altered conditions at the time of forecast (snowpack, precipitation, runoff)
  - Also developed perfect knowledge volumes from streamflows
- Rules Curves
  - Using synthetic volume forecasts, compute synthetic rule curves (flood control, variable energy refill curves)

Model Input: Natural Streamflows at The Dalles for 2020's & 2040's

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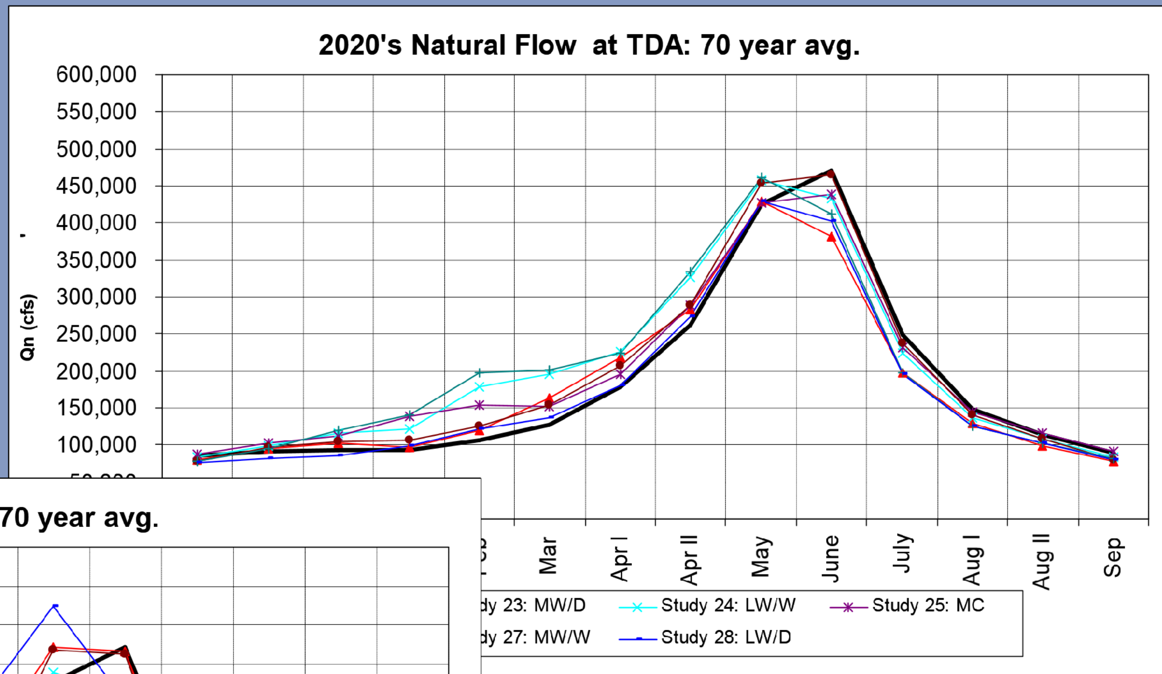
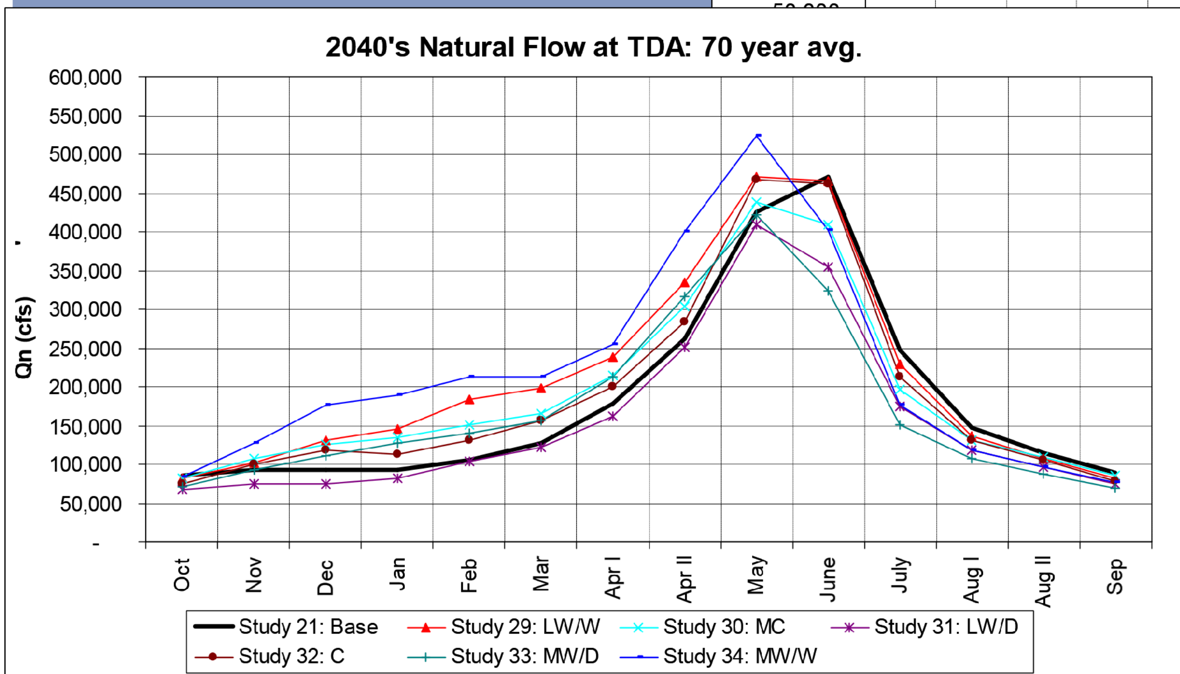
Climate Change scenarios result in higher natural streamflows in the winter to spring period…

and lower streamflows in the summer, generally speaking





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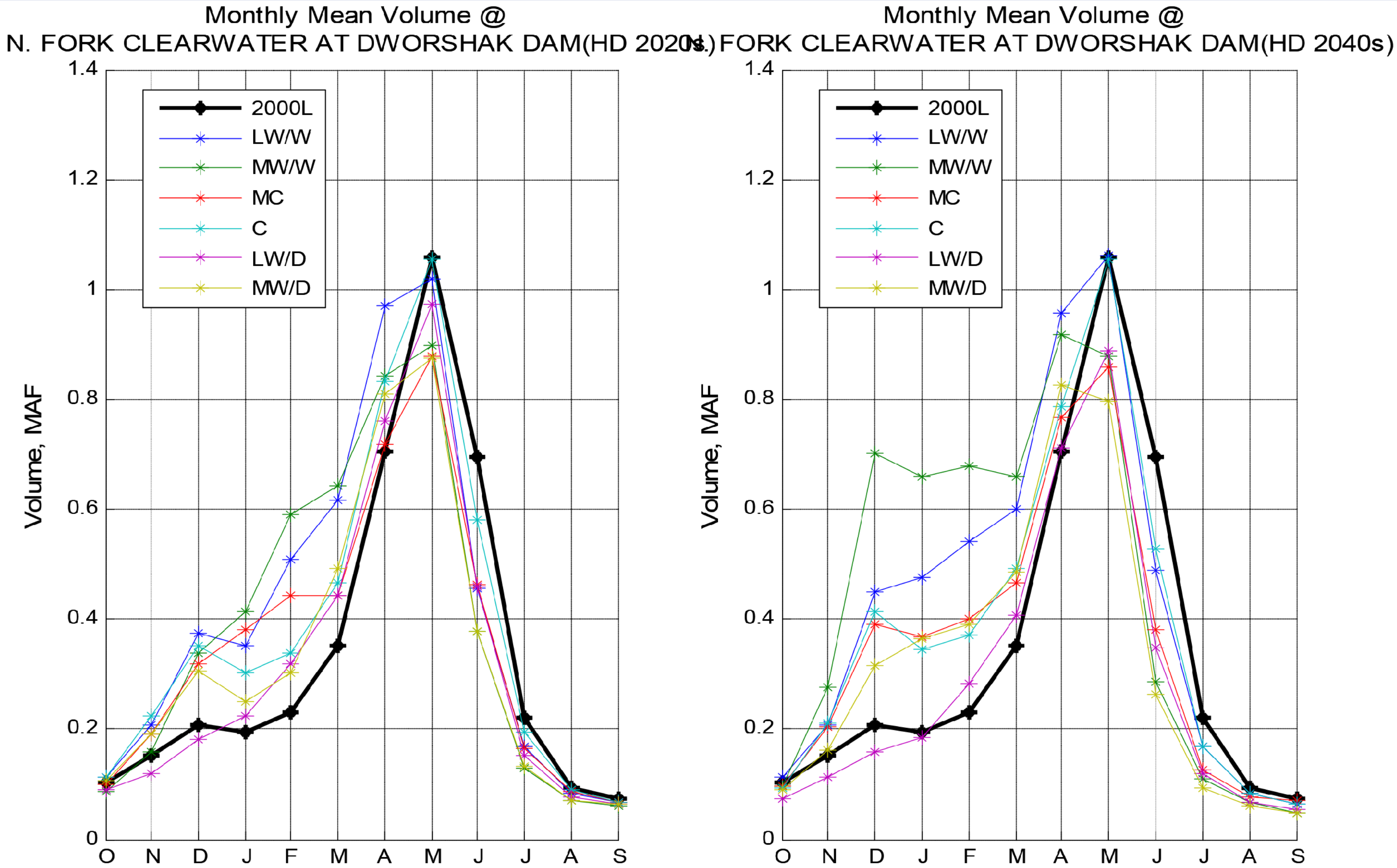
Example of High Winter Runoff and Lower Spring Runoff at Dworshak



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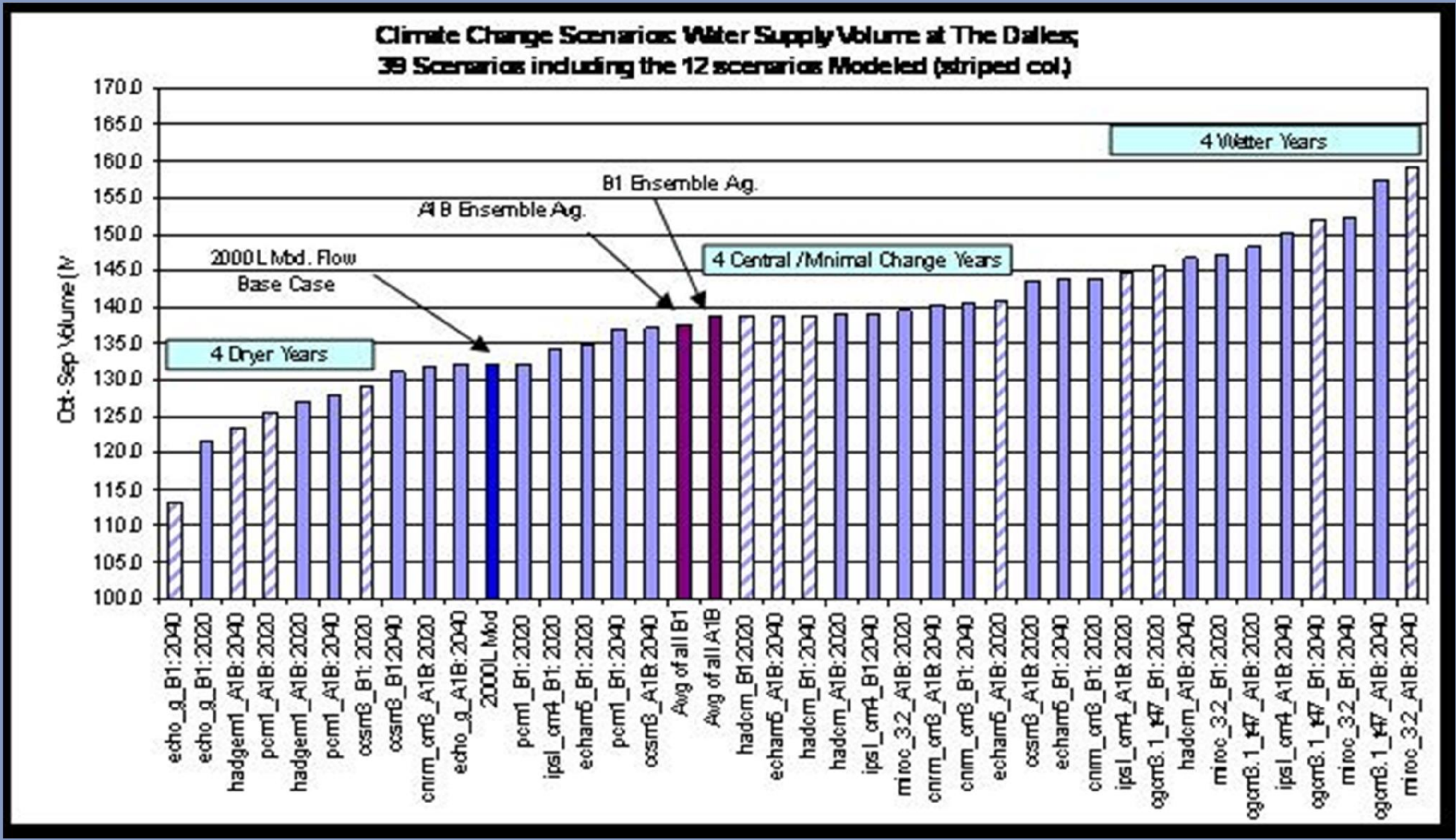
Model Input: Water Year Volume Comparison for Additional Scenarios



The striped columns indicate the 12 Hybrid scenarios modeled (6 ea. For 2020 period, 6 ea. For 2040's)

Model Input: Shape of Runoff for 2020's

Note that the 2040's have similar shaping characteristics

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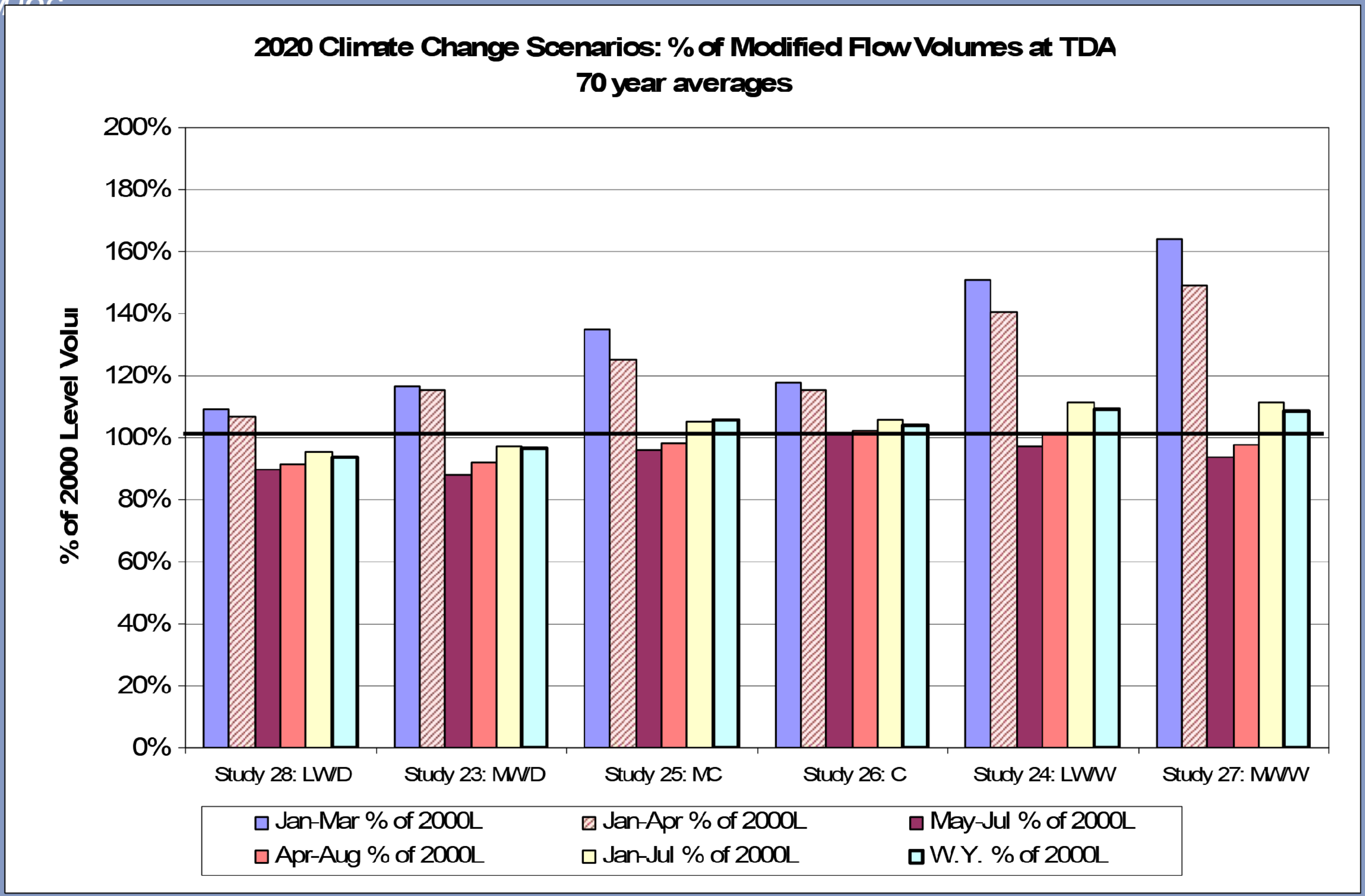

2000L Base Case Volumes @ TDA

Period	Vol (MAF)
Jan-Mar	19.5
Jan-Apr	32.5
May-July	69.4
Apr-Aug	90.5
Jan-July	101.9
Oct-Sep	131.7

Note that the Jan-April period is higher than current levels, the May-July period is lower (earlier runoff)

Overview of Regional Climate Scenario Development
at the Climate Impacts Group
March, 2010

The University of Washington Climate Impacts Group is an internationally recognized interdisciplinary research team studying the impacts of climate variability and climate change on the Pacific Northwest (PNW). For the last 15 years, members of the CIG have won acclaim for their leadership role in climate impacts research, outreach, and education for the region, conducting cutting-edge research at spatial scales ranging from local communities to the entire western U.S. Their research is funded by federal, state, and local sources including major federal grants from NOAA, NSF, EPA, and DOE. This program has yielded more than 300 publications and created an extensive set of tools and scientific resources used by stakeholders, including people in regulatory agencies, resource managers and policy makers, in addressing issues related to climate in the PNW. Key areas of the group's collective expertise include:

- Development of spatially-explicit meteorological data sets for use in resource impacts models
- Statistical downscaling techniques
- Regional climate modeling and the application of regional climate models to dynamically downscale climate change scenarios
- Seasonal to interannual climate variability and forecasting
- Macro scale and fine scale hydrologic modeling
- Water resources modeling and impacts assessment
- Terrestrial and aquatic ecosystem impacts assessment
- Coastal impacts assessment
- Climate change vulnerability assessment and adaptation planning
- Outreach and education programs

The CIG currently provides a wide range of climate change products and services to PNW stakeholders using a suite of statistically and dynamically downscaled climate projections based on global model simulations from the IPCC Fourth Assessment Report (IPCC AR4). In addition to these well-proven approaches, over the last five years the CIG has also developed an innovative, comprehensive, and well-funded regional climate modeling program that provides the foundation for the CIG's cutting-edge experimental downscaling research.

Current Climate Change Products and Services Based on Statistical Downscaling
In collaboration with the Washington State Department of Ecology and a group of regional stakeholders in Oregon, Washington, Idaho, Montana and British Columbia, the CIG is currently completing a two-year climate change study over the Columbia River basin and coastal drainages in Washington and Oregon. The study, which is one of the most comprehensive of its type in the country, provides detailed projections of future hydrologic conditions for 297 river locations in the PNW as well as a regional database of gridded (i.e., spatially-explicit) projections of climatic and hydrologic conditions over the entire study domain (http://www.hydro.washington.edu/2860/). The study chose the ten best-performing global

climate models* for the PNW from the IPCC AR4 and used different global greenhouse gas scenarios and three different statistical downscaling approaches to produce projections for a variety of different future time periods (76 climate change scenarios in all). These scenarios were designed in collaboration with regional decision makers to support water resources planning and terrestrial and aquatic ecosystems research, impacts assessment and planning. The draft study results (which will be finalized this spring) are already being used by a wide range of stakeholders, including the U.S. Geological Survey, Bonneville Power Administration, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Forest Service, U.S. Fish and Wildlife Service, Boise Aquatic Research Laboratory, and the National Marine Fisheries Science Center. Upon finalization of the scenarios, CIG will host a series of workshops introducing the scenarios and their potential applications in greater detail.

Overview of CIG's Downscaling Methods and Ongoing Research

The CIG has been developing effective and well-validated methods of downscaling global climate projections for over ten years, and houses leading research programs for both statistical downscaling and regional climate modeling (dynamic downscaling). These downscaling methods have been applied to the global climate model projections produced for the Third and Fourth IPCC Assessments (TAR and AR4) and will be applied to the Fifth Assessment (AR5/CMIP5) simulations as they become available. We are currently collaborating with the Oregon Climate Change Research Institute (OCCRI) at Oregon State University, Oxford University and the Hadley Centre in the United Kingdom to develop a regional version of the Oxford/Hadley global ClimatePrediction.net system for volunteer computing. CIG also uses a variety of publically available regional climate products from other research groups. These include simulations from the North American Regional Climate Change Assessment Program (NARCCAP) regional climate simulations and statistical downscaling results (*e.g.,* using the BCSD approach discussed below) from several sources. Although closely related to the downscaling approaches used by the CIG, both typically are of coarser resolution than the current CIG methods.

The CIG's suite of downscaling approaches includes:

1) **Statistical Downscaling.** An improved version of the Bias-Correction Spatial Downscaling (BCSD) method (Elsner *et al.*, 2010; Salathe *et al.*, 2007; Salathé, 2003; 2005; Widmann *et al.*, 2003; Wood *et al.*, 2004) has been developed at CIG and is also used by several other research groups. The current version of this method produces daily minimum/maximum temperature and precipitation on a 1/16-degree grid (roughly 5 km x 6 km; 3 x 3.6 miles) for the Columbia, Missouri, and Colorado basins. Several approaches have recently been developed to temporally downscale the monthly-mean model output to daily time steps, which produce significantly more realistic hydroclimate results than previous methods (Hamlet *et al.*, in prep.). The output from these downscaling approaches can be used directly as input to hydrologic models such as VIC, DHSVM, or those used by other researchers, water resource agencies, etc. As noted above, a large suite of hydroclimate scenarios using AR4 (CMIP3) global climate simulations (10 models and two emissions scenarios) and three statistical downscaling methods

* The 10 best models are selected according to their performance at simulating the observed 20th century climate.

are now available on-line (http://www.hydro.washington.edu/2860/). New simulations for the IPCC AR5 will be downscaled as they become available.

2) **WRF Regional Climate Modeling.** Regional climate model simulations using MM5 and now the WRF model have been underway for the past five years at CIG (Salathé *et al.*, 2007; Salathé *et al.*, 2008; Salathé *et al.*, 2009; Zhang *et al.*, 2009), building on the long-standing mesoscale weather forecasting system at the University of Washington (Mass *et al.*, 2003) and in collaboration with Pacific Northwest National Lab (PNNL) (Leung *et al.*, 1999; Wood *et al.*, 2004). Due to the computational demands inherent in regional climate modeling, only a few global simulations have been downscaled using this method. Currently, we have three 100-year scenarios simulated over the western United States. However, due to recent advances in regional climate modeling and computing power, we are now constructing a larger ensemble of simulations. Results are 3-hourly surface fields (*e.g.,* temperature, precipitation, winds, snow cover, soil moisture) and 6-hourly upper atmospheric fields on a 12-km grid over the Pacific Northwest and 36-km over the western United States. New simulations for the IPCC AR5 and coarse-resolution NARCCAP simulations will be dynamically downscaled using the WRF model as they become available. The high spatial resolution and frequent time step of the output allows the WRF results to be used in a wide range of climate impacts studies such as air quality modeling (Avise *et al.*, 2009; Chen *et al.*, 2009), urban stormwater management (Rosenberg *et al.* 2010), and fine-scale hydrologic modeling. This model is also a valuable tool for research on small-scale climate processes unique to our region.

3) **Regional ClimatePrediction.net** The ClimatePrediction.net (CPDN) project is a joint effort between Oxford University and the Hadley Centre in the United Kingdom to engage volunteers in running a climate model on their personal computers and generate very large climate ensemble experiments. In 2007, Oxford/Hadley Centre formed partnerships to develop regional versions of CPDN (regCPDN). A western U.S. project has been formed as a collaboration between OCCRI at Oregon State University, CIG, and Climate Central. The regCPDN modeling system is still in development; a beta version is expected in Spring 2010 with a full release by Summer 2010. This project will provide a very large ensemble of simulations of the regional climate to allow better understanding of uncertainties in regional climate projections. Volunteers will perform one-year climate simulations for current and future conditions; based on previous CPDN experiments, we anticipate well over 1000 volunteers. Results will include monthly-mean values and annualized statistics on a 25-km grid covering the US West. Output variables have been selected with societal and environmental applications in mind and include parameters for the mean surface climate (minimum and maximum temperature, precipitation, winds, humidity, and pressure), the jet stream, extreme weather (temperature, precipitation, winds), the hydrologic cycle, and coastal upwelling.

In contrast to the Bias-Correction Spatial Downscaling method and the WRF regional climate model, the regCPDN is not a downscaling method, but a system for generating a large ensemble of regional climate simulations using an integrated global atmospheric model (HadAM) and embedded regional model (HadRM). Different ensemble members will be produced by altering initial conditions or numerical parameters in the model. Thus, AR4 or AR5 global climate models will not be downscaled with this method. Output variables will be suitable for many climate impacts applications; however, this project will not produce daily or hourly data and full three-dimensional atmospheric fields that are required for some modeling applications, such as air quality. As such, the regCPDN program complements traditional RCM studies that can produce more detailed results, but for much smaller ensembles.

Statistical Downscaling and Regional Climate Modeling

While regional climate models (RCMs) allow for significantly better treatment of topographic influences on regional climate when compared with coarser-resolution global climate models, additional uncertainties and biases are introduced by RCMs. Furthermore, it is important to recognize that even the highest-resolution regional climate models are too coarse for many impacts studies. Consequently, as shown in Wood et al. (2004), it is not simply a question of choosing to use either statistical downscaling or dynamical downscaling with RCMs to provide climate change scenarios needed for impacts assessments. For most applications, RCM results must be statistically downscaled and bias corrected to produce climate scenario output appropriate for impacts applications.

Uncertainties in global climate model projections are a major consideration in climate impacts studies. Because dynamical downscaling with RCMs requires a great deal of computer time, few global climate model scenarios have been dynamically downscaled, and the range of scenarios examined this way is currently limited. In contrast, statistical downscaling (*e.g.,* BCSD) requires only modest computing power and therefore allows for downscaling many global climate model projections, which is important for sampling the uncertainty that currently exists in future climate projections. Additionally, the BCSD downscaling method does not add additional uncertainty to the climate projection; this method formally maps the climate change signal from the global model onto the observed regional climate patterns. RCMs simulate fine-scale weather processes that interact with terrain features that are important to local impacts and extreme events, factors that are at best poorly represented in coarse-resolution global climate models in regions with rugged terrain like western North America. Thus, RCMs create more diversity in climate projections by adding more pathways for local climate change to be expressed even when constrained by the output from a coarser-resolution global climate model. In this way, statistical BCSD downscaling and RCMs are highly complementary methods for developing high-resolution regional climate scenarios that are useful for local to regional scale climate change impacts assessments.

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Table 1. Downscaling products used at University of Washington, Climate Impacts Group.

Method	Institutions	Grid Spacing	Time Step	Time Coverage	Scenarios	Data Available
Statistical (BCSD)	UW CIG	1/16-degree (approx 6 km)	Daily	1900-2100	AR4 (CMIP3) AR5 (CMI5) when available	http://www.hydro.washington.edu/2860/
WRF RCM	UW CIG	36 km US West 12 km PNW	3-hourly Some hourly	1970-2070	AR4/AR5 models 4 currently 12+ planned	http://cses.washington.edu/data/pnwrcm (complete data on request)
Regional CPDN	OSU OCCRI UW CIG	25 km US West	Monthly and annual average statistics	1-year time slices current and future	Single model. 1000+ realizations (dependent on volunteers)	Anticipated late 2010 http://climateprediction.net/content/regional-model
NARCCAP	NCAR, Various	50 km North America	3-hourly	1971-2000 2041-2070	AR4 Models 12 Planned	http://www.narccap.ucar.edu/

FEDERAL COLUMBIA RIVER POWER SYSTEM
FCRPS
RMJOC

Climate and Hydrology Dataset for use in Agencies' Longer-Term Planning Studies

Climate Change Collaboration (C3) Meeting
Nancy Stephan
Bonneville Power Administration
September 22, 2009
Portland Oregon

RMJOC

Applications

Alternative climate change data sets for:

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- Bi-Op assessments
- ESA/NEPA
- Reliability Studies
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RMJOC

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- Motive
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RMJOC

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RMJOC

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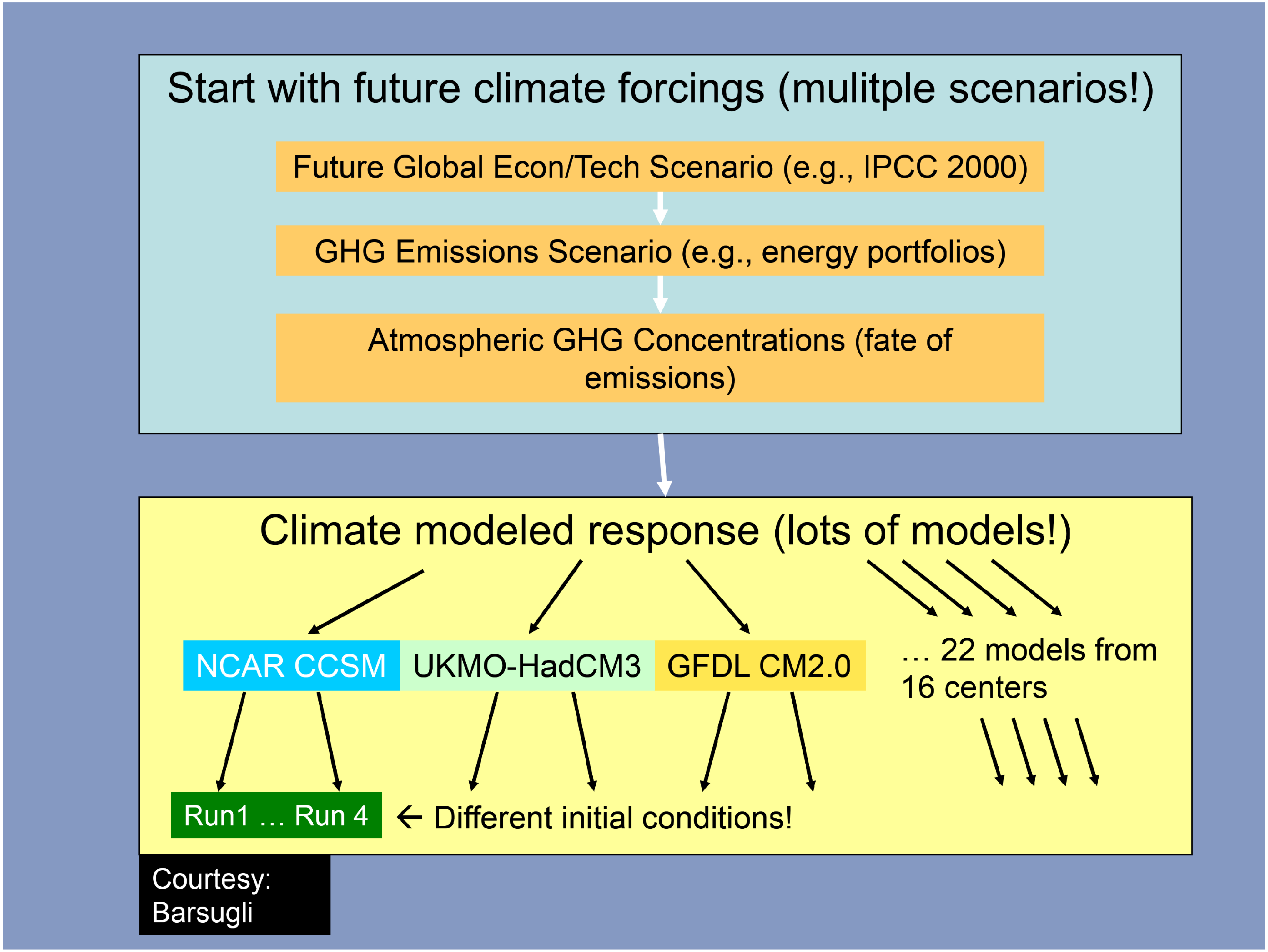
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RMJOC

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RMJOC

U of W Model Selection

Model

UKMO-HadCM3
CNRM-CM3
ECHAM5/MPI-OM
ECHO-G
PCM
CGCM3.1(T47)
CCSM3
IPSL-CM4
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The five best of these based on bias and North Pacific variability only:

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RMJOC

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RMJOC

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  - Compare results – consider various longer-term planning efforts undertaken by RMJOC agencies and which type is most appropriate

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(Assumptions: Start Date = 1 October 2009; U
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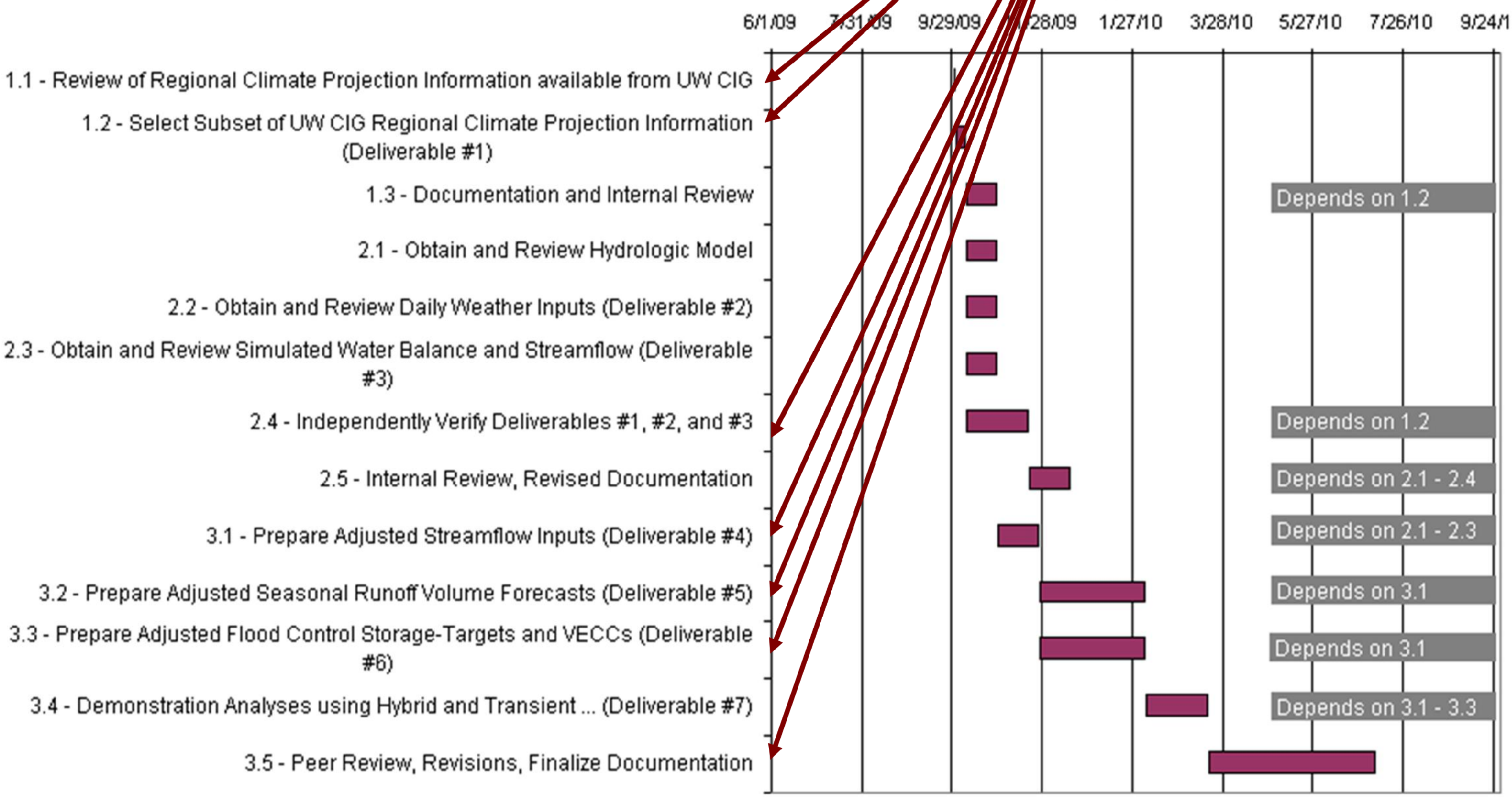

RMJOC

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RMJOC

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RMJOC

Questions?

RMJOC

RMJOC Climate and Hydrology Dataset for use in Agencies' Longer-Term Planning Studies

OCCRI Workshop on Scenarios of Future Climate

Nancy Stephan
Bonneville Power Administration
October 6th, 2009
Portland Oregon

Applications

RMJOC

Alternative climate change data sets for:

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RMJOC

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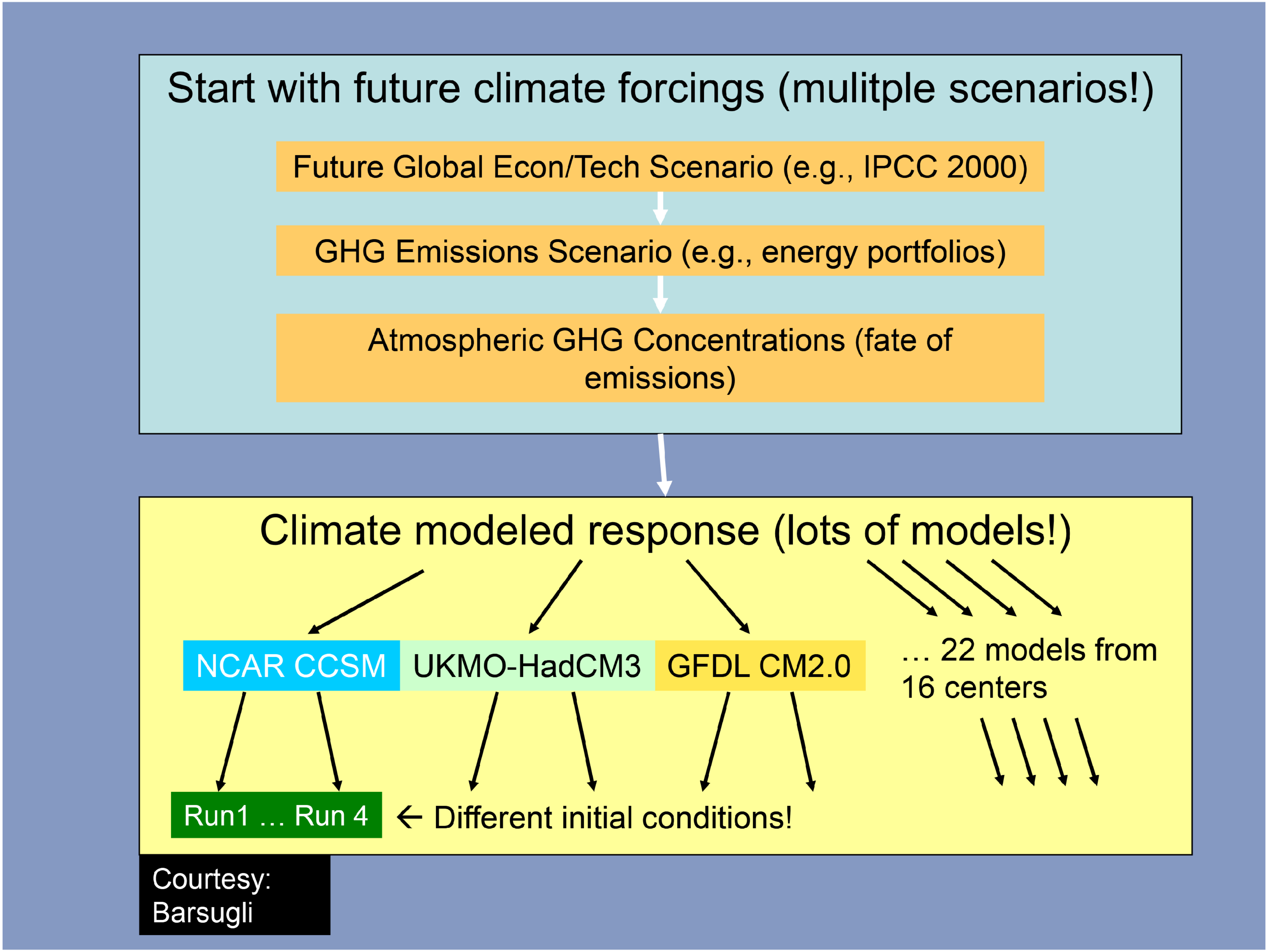
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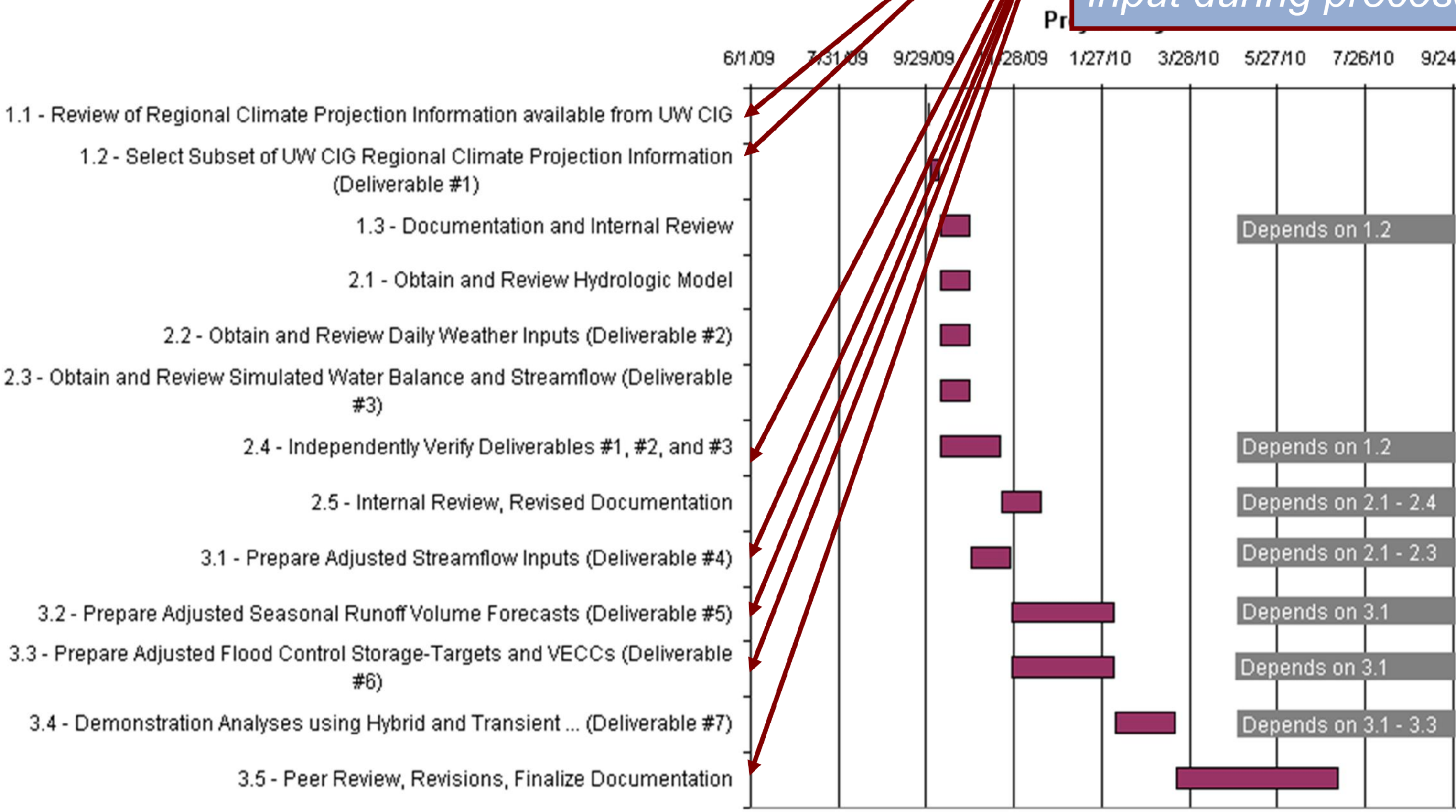

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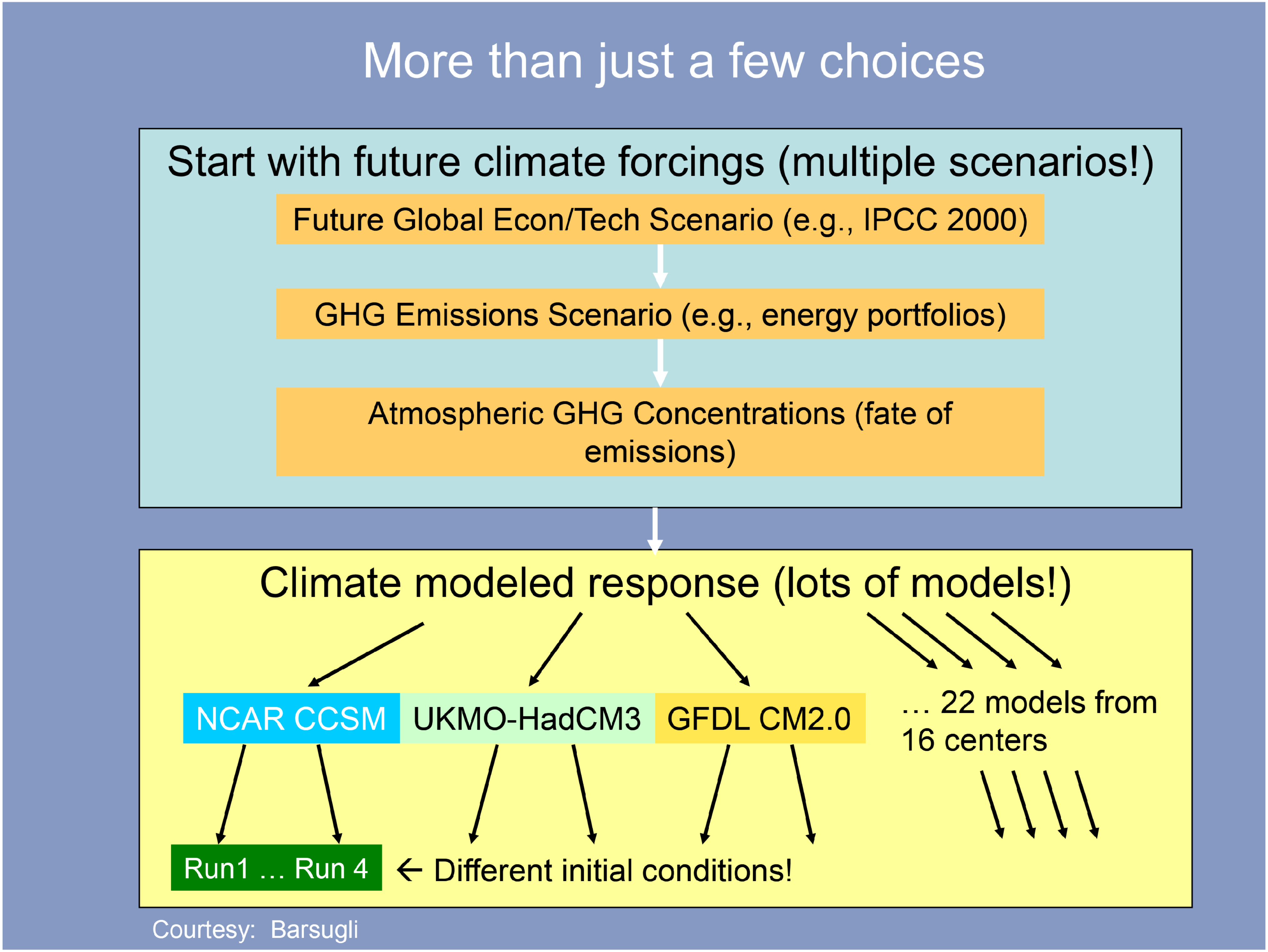
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- Task 3.3 – Storage-Targets for Flood Control, Energy Content Curves (Deliverable #6)
- Task 3.4 – Demonstration Analyses (Deliverable #7)
- Task 3.5 – Peer Review, Revisions, Documentation

RMJOC

Deliverables

- Data adopted from CIG (RMJOC reviewed, documented)
  - (#1) Subset of UW CIG Regional Climate Projection Information
    - Step-change in climate (“hybrid”)
    - Time-developing climate (“transient”)
  - (#2) Daily weather inputs for hydrologic modeling (both types)
  - (#3) Daily hydrologic modeling results (both types)
- Data developed by RMJOC agencies (extending from both types)
  - (#4) Streamflows bias-corrected or adjusted for reservoir operations/regulation modeling
  - (#5) Seasonal runoff volume forecasts
  - (#6) Develop Flood Control and Operating Rule Curves
- (#7) Demonstration Study by RMJOC agencies’ staff
  - Inputs associated with both data types (Hybrid, Transient)
  - Compare results – consider various longer-term planning efforts undertaken by RMJOC agencies and which type is most appropriate

RMJOC

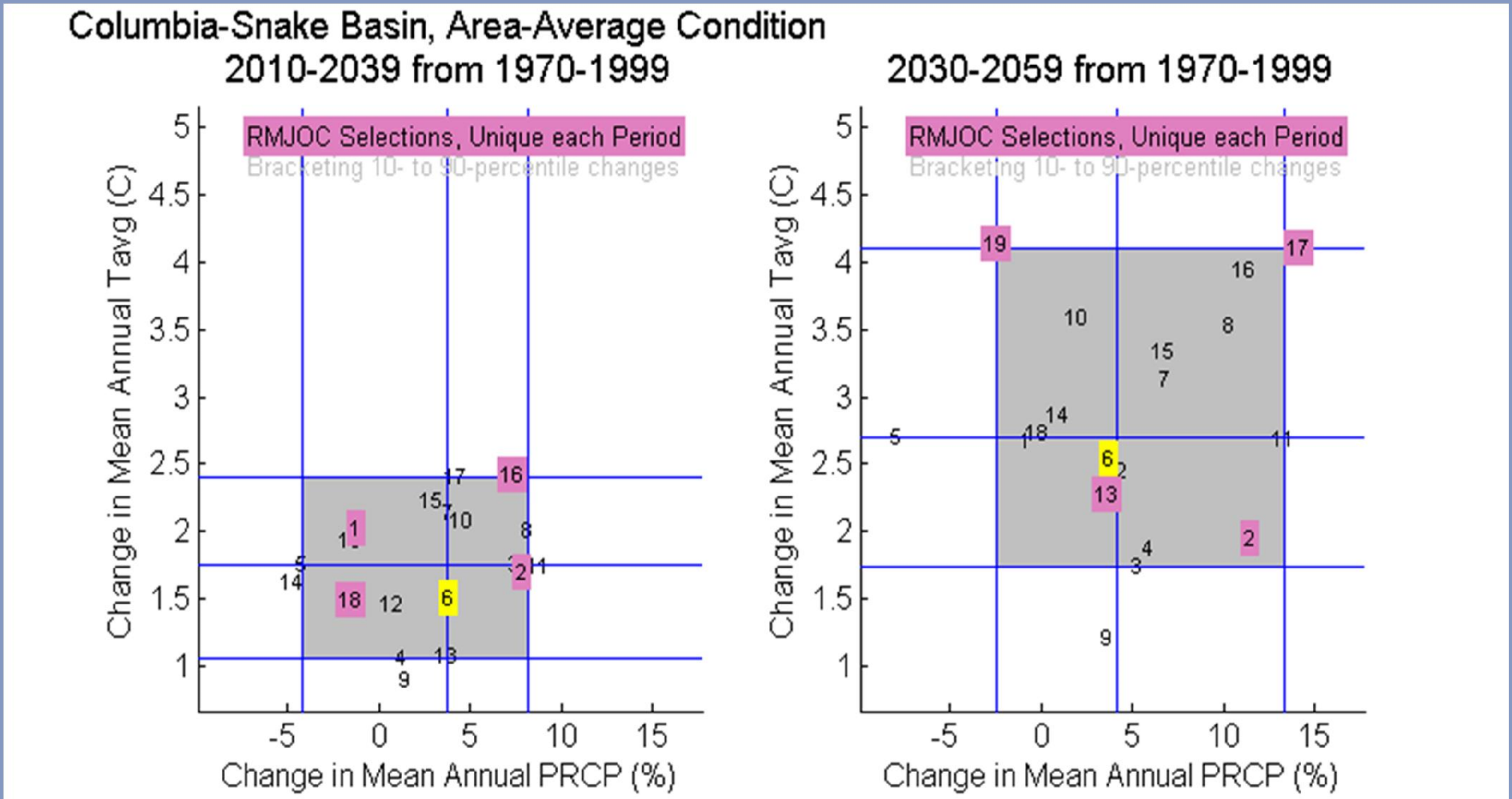
Work Plan Development and Implementation

- Internal Review
  - Executive's Meeting – May 21
  - Technical and Planning Staff review – May 6-27
  - Incorporate Review Comments – Aug 15
- External Review
  - Orientation Workshop – June 9 (CIG to participate)
  - External review period – June-August
  - Incorporate Review Comments – August-September
- Work Plan Implementation
  - October 16^{th} (tasks 1.1 and 1.2)
  - December 7^{th} (task1.2 results, task 2 progress, discuss task 3)

RMJOC

How to make a selection….

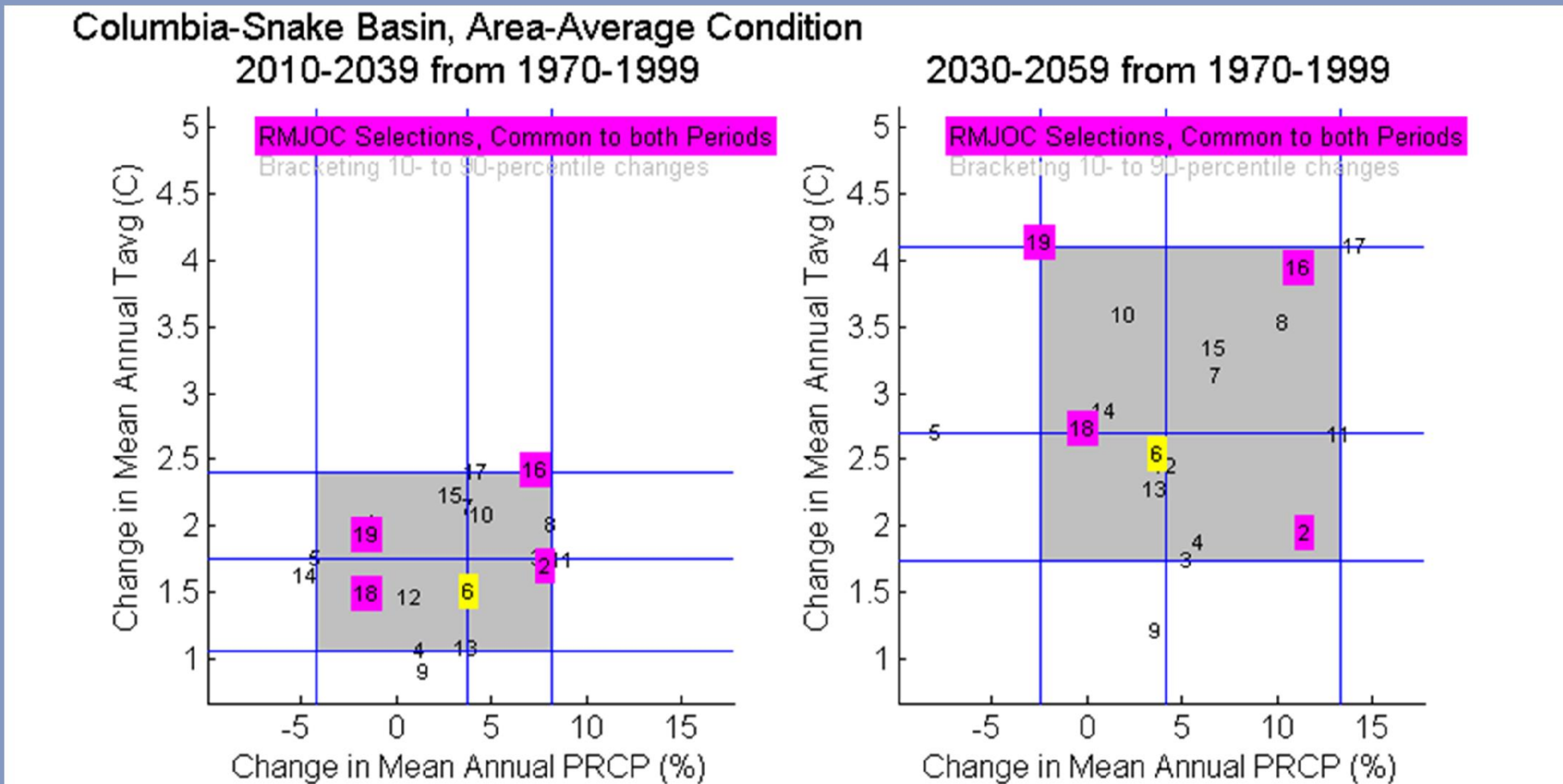
10 and 90 percentile brackets/Unique to each period?



RMJOC

How to make a selection….

10 and 90 percentile brackets/Common to each period?



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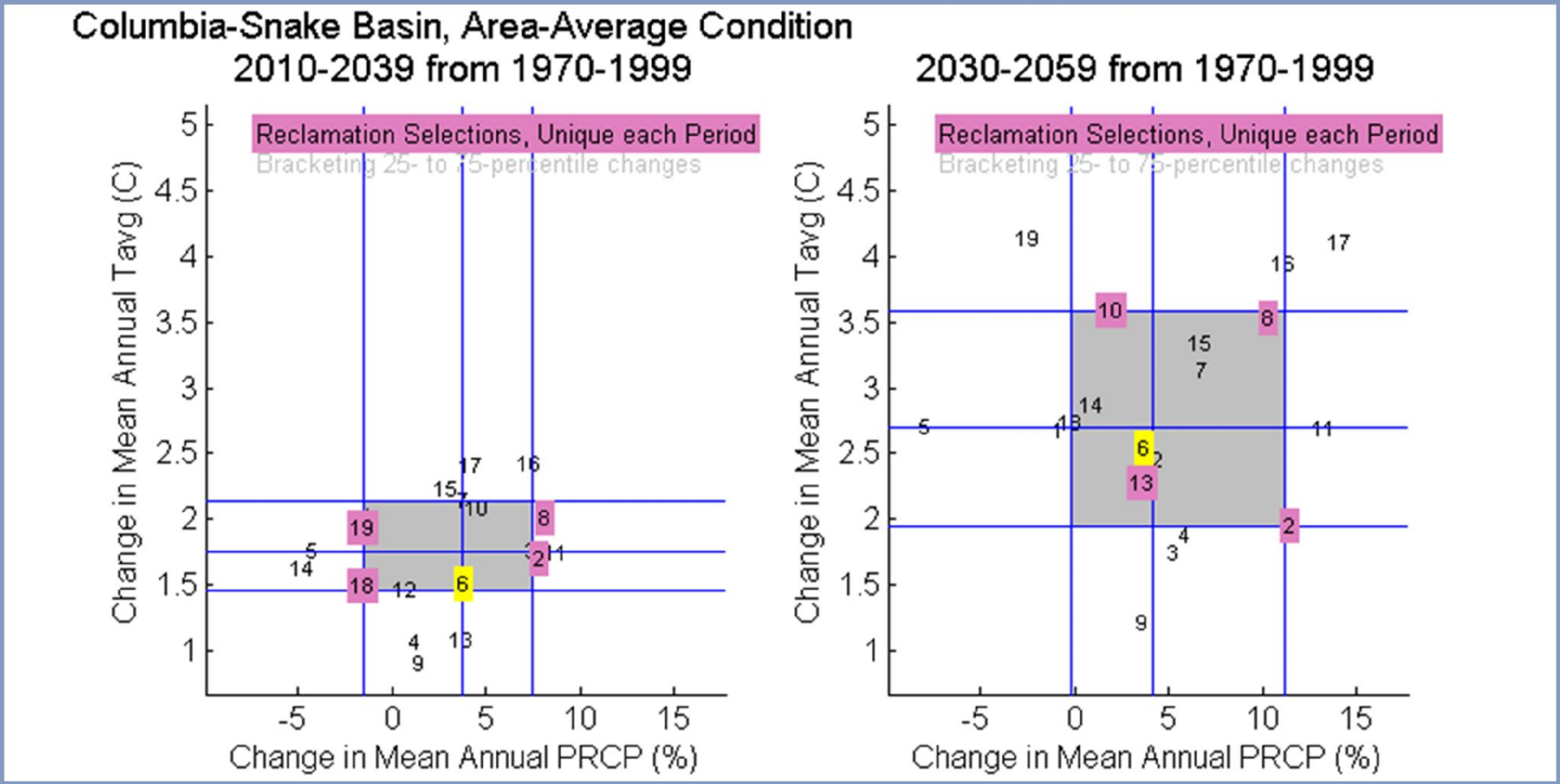
RMJOC

How to make a selection….

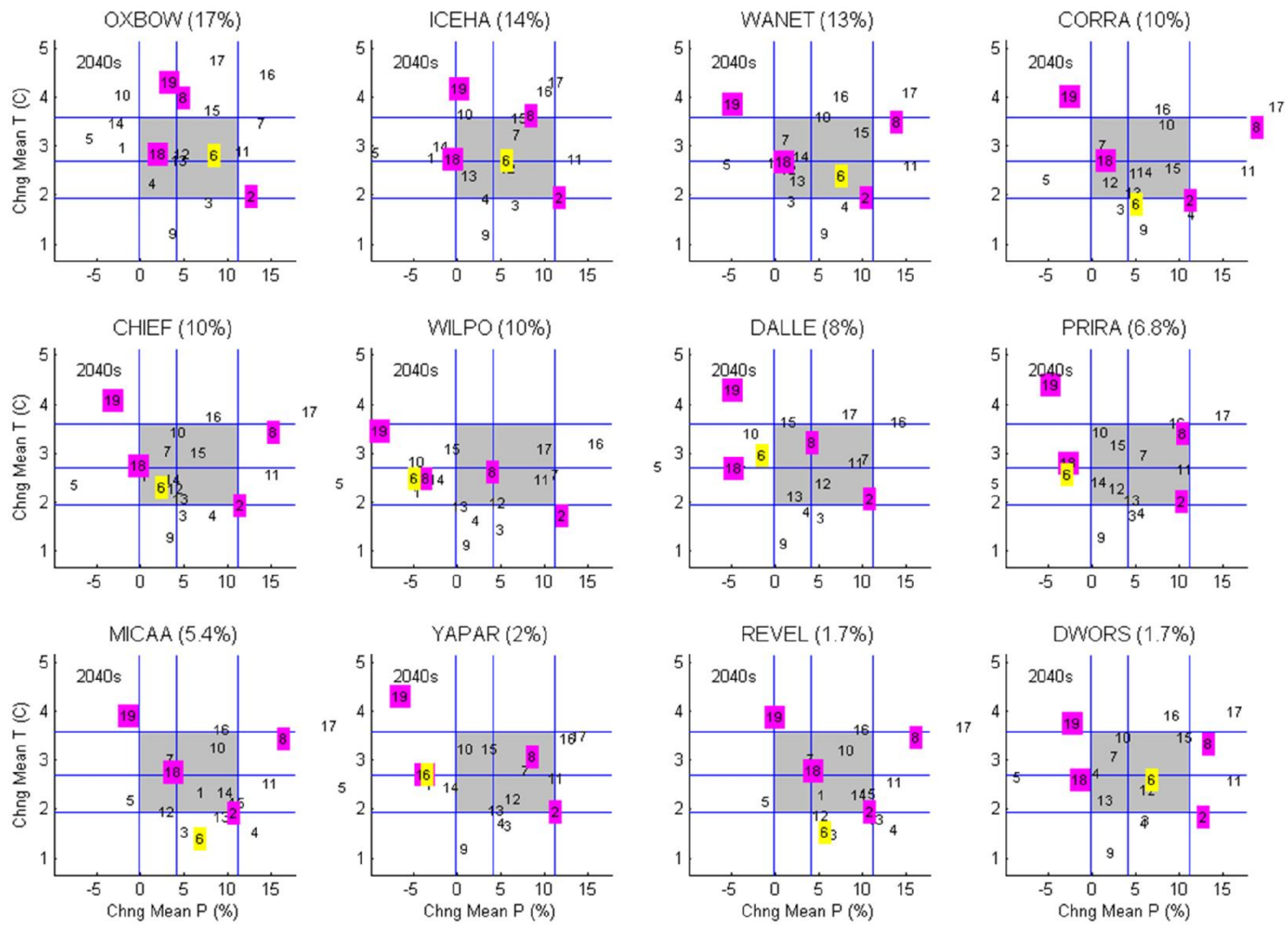
25 and 75 percentile brackets/Unique to each period?



RMJOC

How to make a selection….

How do these map out by sub-basins?



Summary of Projections Selected

				Hybrid Selections						
				2020s			2040s			
Number		GCM [2]	Emissions Scenario	Selected (Labels) [3]	Change in P (in) [4]	Change in T (°C)	Selected (Labels)	Change in P (in)	Change in T (°C)	Transient (x = selected, o = not selected)
1	√	ccsm3	B1	MW/D	-1.2	1.4		-0.8	1.8	x
2	√	cgcm3.1 t47	B1	LW/W	7.9	1.1	LW/W	11.5	1.3	x
3		cnrm cm3	B1		7.5	1.2		5.3	1.2	o
4		echam5	B1		1.3	0.7		5.9	1.2	o
5	√	echo g	B1		-4.2	1.2	LW/D	-7.9	1.8	x
6	√	hadcm	B1	C	3.8	1.0	C	3.7	1.7	x
7		ipsl cm4	B1		3.8	1.4		6.9	2.1	
8		miroc 3.2	B1		8.1	1.3		10.4	2.3	
9		pcm1	B1		1.5	0.6		3.6	0.8	o
10		ccsm3	A1b		4.6	1.4		2.0	2.4	o
11		cgcm3.1 t47	A1b		8.8	1.2		13.4	1.8	o
12		cnrm cm3	A1b		0.8	1.0		4.1	1.6	o
13	√	echam5	A1b	MC	3.7	0.7	MC	3.7	1.5	x
14		echo g	A1b		-4.7	1.1		0.9	1.9	o
15		hadcm	A1b		3.0	1.5		6.7	2.2	o
16	√	ipsl cm4	A1b	MW/W	7.4	1.6		11.2	2.6	
17	√	miroc 3.2	A1b		4.2	1.6	MW/W	14.2	2.7	
18	√	pcm1	A1b	LW/D	-1.5	1.0		-0.2	1.8	x
19 [1]	√	hadgem1	A1b		-1.5	1.3	MW/D	-2.5	2.8	

Notes

[1] Number 19 was not included in Oct 24 workbook shared with stakeholders.

[2] Green shaded GCMs are those that BC Hydro suggested as being part of a "better set of GCMs." (Dec 2, Frank Weber email)

[3] Selected Labels: MW = More Warming, LW = Less Warming, W = Wetter, D = Drier, MC = Minor Change, C = Central Change

[4] P = precipitation, T = average daily temperature, "Change in" means change in 92-year period-mean annual condition. For assessing change, the reference is Observed Climate Variability, 1916-2006. The changed condition is the 92-year Observed Climate Variability sequence adjusted to match climate characteristics of a projected 30-year period (2020s = 2010-2039 and 2040s = 2030-2059) from the given underlying climate projection (column Number).

RMJOC

Project Status

TASK	STATUS
1.1 Review of Climate Projection Information from US CIG	COMPLETE
1.2 Selection of Subset	COMPLETE
1.3 Documentation and Internal Review	In progress (2/3)
2.1 Obtain/review hydrologic mode (VIC)	In progress (not on CP)
2.2 Obtain and review daily weather inputs	COMPLETE
2.3 Obtain/review simulated water balance and streamflow	Obtain –COMPLETE Review – in progress
3.0 Bias-correct CIG data to natural flow values	In progress
3.1 Prepare Modified Inflows	Waiting on 3.0 (3.4?)
3.2 Prepare seasonal runoff volume forecasts	Waiting on 3.0
3.3 Compute FC targets and VECC	Waiting on 3.2
3.4 Demonstration Analyses	Waiting on 3.0, 3.1, 3.2, 3.3

RMJOC

Climate and Hydrology Dataset for use in Agencies' Longer-Term Planning Studies

"Responding to Climate Variability and Change: A Prototype for Trans-boundary Assessment and Services in the Columbia River Basin"

Nancy Stephan
Bonneville Power Administration
October 6th, 2009
Portland Oregon

Applications

RMJOC

Alternative climate change data sets for:

- 2014/2024 Columbia River Treaty Review
- Bi-Op assessments
- ESA/NEPA
- Reliability Studies
- Flood Risk Management
- Rates/Revenues
- Infrastructure Studies

RMJOC

RMJOC Motive and Need

- Motive
  - consistent incorporation of climate projection information into Agencies' longer-term planning studies
- Need
  - adopt common dataset (climate and hydrology)
  - establish consensus methods for data use
  - efficiently use limited resources through coordinated development of data and methods

RMJOC

Project Team

	RMJOC Agency		
	BPA	Reclamation	USACE NWD
Sponsor	Rick Pendergrass	Pat McGrane	Jim Barton
Liaison to Programs, Planning, Policy	Rick Pendergrass Birgit Koehler, Nancy Stephan	Pat McGrane	Peter Brooks Seshu Vaddey
Technical Coordinator	Nancy Stephan	Levi Brekke	Seshu Vaddey Randy Wortman
Technical Implementation	PGP staff	Leslie Stillwater, Tom Pruitt, potentially others	Mix of Northwestern Division and District staff

RMJOC

Key Scoping Decisions

1. Use CIG's forthcoming data on regional climate and hydrology (CIG's "HB2860" regional project)

2. Use two methodologies from CIG
   - Step-change climate information (Hybrid)
   - Time-developing climate information (Transient)

3. Use only a subset of both data sets

4. Conduct demonstration analysis using both types to draw impressions on which types are more appropriate for various types of Agencies' longer-term planning

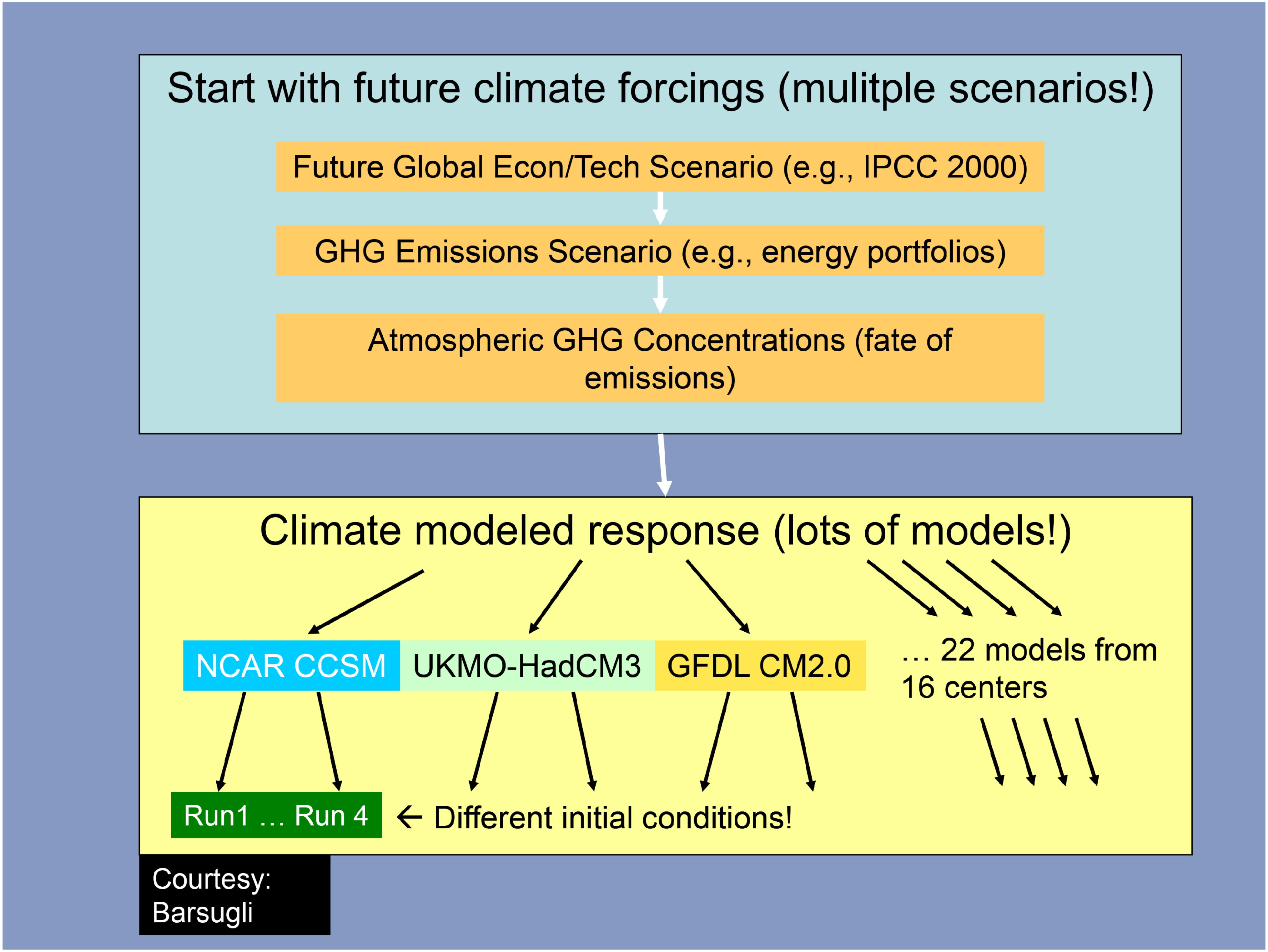
RMJOC

TASK 1 - CLIMATE PROJECTIONS SURVEY AND SELECTION

- Task 1.1 - Review of Regional Climate Projection Information available from UW CIG
- Task 1.2 - Select Subset of UW CIG Regional Climate Projection Information (Deliverable #1)
- Task 1.3 - Documentation and Internal Review

Costs per Agency

– BPA	$11K
– USACE	$12K
– Reclamation	$15K (lead)


Start with future climate forcings (mulitple scenarios!)
Future Global Econ/Tech Scenario (e.g., IPCC 2000)
GHG Emissions Scenario (e.g., energy portfolios)
Atmospheric GHG Concentrations (fate of emissions)
Climate modeled response (lots of models!)
NCAR CCSM
UKMO-HadCM3
GFDL CM2.0
… 22 models from 16 centers
Run1 … Run 4
← Different initial conditions!
Courtesy: Barsugli

FEDERAL COLUMBIA RIVER POWER SYSTEM
FCRPS

RMJOC

What subsets are appropriate for planning purposes?
Which data type is best for each planning study?

"*Hybrid*" or step-change data ("climate change")

20 Climate Projections

10 Global Climate Models X **A1b and B1 emission scenarios** X **sampled changes from 1971-2000 to either… 2010-2039 2040-2069**

= 40 "climate change" hydrologic scenarios, each 70 years in duration, having variability as observed from 1916-2003

"*Transient*" or time-developing

10 Climate Projections

5 Global Climate Models X **A1b and B1 emission scenarios**

= 10 hydrologic "projections", continuous from historical to future (1950-2099), having Global Climate Model variability

RMJOC

TASK 2 - HYDROLOGIC DATA SELECTION AND VERIFICATION

- Task 2.1 – Obtain and Review Hydrologic Model
- Task 2.2 – Obtain and Review Daily Weather Inputs (Deliverable #2)
- Task 2.3 - Obtain and Review Simulated Water Balance and Streamflow (Deliverable #3)
- Task 2.4 - Independently Verify Datasets #1, #2, and #3
- Task 2.5 - Internal Review, Revised Documentation

Costs per Agency

- BPA $16K
- USACE $18K
- Reclamation $38K (lead, implementing 2.4)

RMJOC

U of W Model Selection

Model

UKMO-HadCM3
CNRM-CM3
ECHAM5/MPI-OM
ECHO-G
PCM
CGCM3.1(T47)
CCSM3
IPSL-CM4
MIROC3.2(medres)
UKMO-HadGEM1

The five best of these based on bias and North Pacific variability only:

UKMO-HadCM3
CNRM-CM3
ECHAM5/MPI-OM
ECHO-G
CGCM3.1(T47)

RMJOC

TASK 3 - OPERATIONS ANALYSES PREPARATION AND DEMONSTRATION

- Task 3.1 – Prepare Adjusted Inflows (Deliverable #4)
- Task 3.2 – Prepare Seasonal Runoff Volume Forecasts (Deliverable #5)
- Task 3.3 –Storage-Targets for Flood Control, Energy Content Curves (Deliverable #6)
- Task 3.4 – Demonstration Analyses (Deliverable #7)
- Task 3.5 – Peer Review, Revisions, Documentation

Costs per Agency

- BPA $86K
- USACE $160K (extra time required in Tasks 3.2 and 3.3)
- Reclamation $110K (extra time required in Task 3.2)

Deliverables

RMJOC

- Data adopted from CIG (RMJOC reviewed, documented)
  - (#1) Monthly regional climate data (two types)
    - Step-change in climate ("hybrid")
    - Time-developing climate ("transient")
  - (#2) Daily weather inputs for hydrologic modeling (both types)
  - (#3) Daily hydrologic modeling results (both types)
- Data developed by RMJOC agencies (extending from both types)
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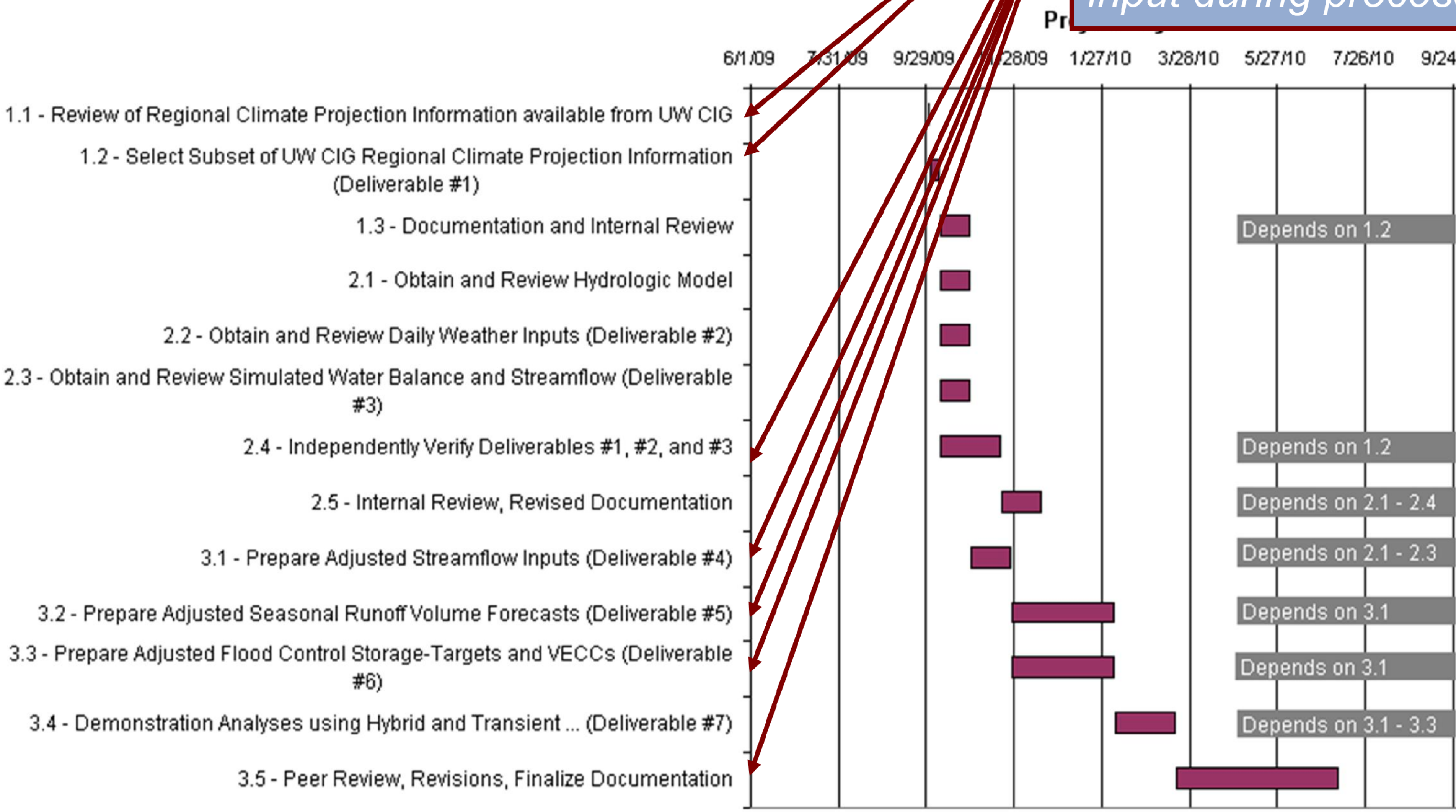
- (#7) Demonstration Study by RMJOC agencies' staff
  - Inputs associated with both data types (Hybrid, Transient)
  - Compare results – consider various longer-term planning efforts undertaken by RMJOC agencies and which type is most appropriate

SCHEDULE

(Assumptions: Start Date = 1 October 2009; U
available 1 October 2009)

Meetings with
Collaborators scoped i
Tasks 1.1, 1.2, 2.4, 3.1,
3.2, 3.3 and 3.5

*(opportunity for externa
input during process)*



FCRPS
FEDERAL COLUMBIA RIVER POWER SYSTEM
RMJOC

Work Plan Finalization

- Internal Review
  - Executive's Meeting – May 21
  - Technical and Planning Staff review – May 6-27
  - Incorporate Review Comments – Aug 15
- External Review
  - Orientation Workshop – June 9 (CIG to participate)
  - External review period – June-August
  - Incorporate Review Comments – August-September
- Work Plan Implementation
  - October 16th (tasks 1.1 and 1.2)

RMJOC

June 9 Attendees

- Corps (Districts and Division)
- BPA
- BOR
- NWRFC
- FWS
- NOAA Fisheries
- Columbia River Inter-Tribal Fish Commission
- Northwest Power and Conservation Council
- NRCS
- BC Hydro

RMJOC

Questions?

Bonneville Power Administration Climate Change Modeling Efforts

Nancy Stephan

RMJOC Climate Change Workshop

May 6th, 2008

Why is Climate Change Modeling Important?

The nature of global climate change and public awareness of the impacts of climate change on water resources has grown in recent years, the need to incorporate climate change scenarios in water planning efforts and policy decisions has been widely acknowledged. In order to assess the potential impacts to the FCRPS, a foundation of sound climate change modeling is necessary.

What Will Potentially be Avoided?

- *Legal and political challenges to major policy decisions, strategic planning, and system operations based on the lack of consideration of climate change in planning and proposed actions.*
- *Potentially costly and un-informed decision making due to the lack of accurate system modeling and conclusions as to the impacts of climate change on the FCRPS*

Joint Effort with University of Washington And Washington Department of Ecology

- University of Washington/Climate Impacts Group/Dept. of Civil and Environmental Engineering
- WA State Department of Ecology
- Bonneville Power Administration
- Northwest Power and Conservation Council
- State of Oregon
- Province of British Columbia (BC Hydro and The Ministry of Environment)

Joint Effort with University of Washington and Washington Department of Ecology

A2 and B1 Scenarios **x** 10 GCM Models **x** 2020 2050 2080

= 60 Sets

16th degree resolution

200 Sites

In the Meantime….

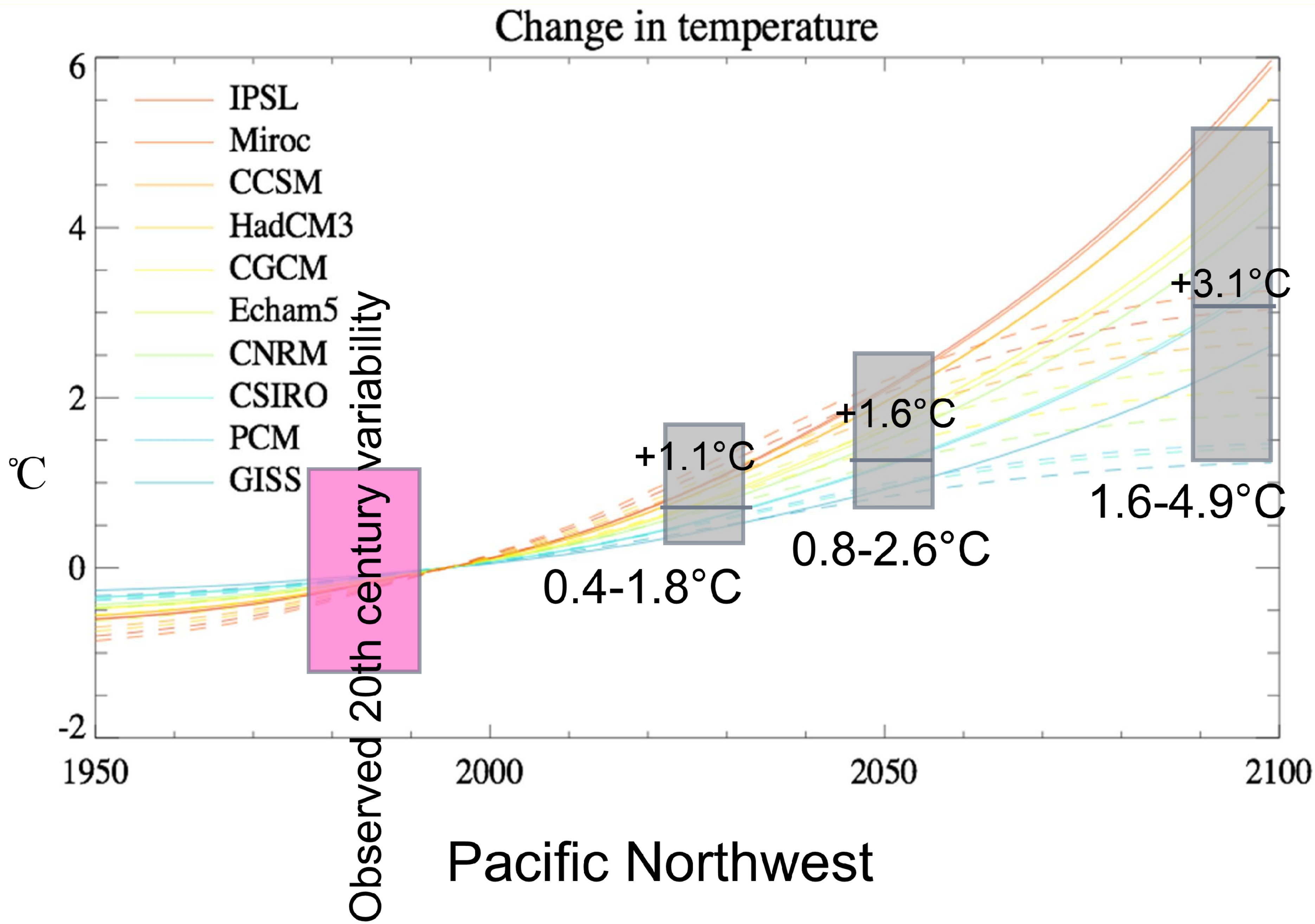
IPCC Fourth Assessment Report
Scenarios and Projected Changes for the Pacific NW[1]

2020	Temperature	Precipitation
Low	0.7 °F (0.4 ℃)	-4%
Medium	1.9 °F (1.1 ℃)	+2%
High	3.2 °F (1.8 ℃)	+6%

2040	Temperature	Precipitation
Low	1.4 °F (0.8 ℃)	-4%
Medium	2.9 °F (1.6 ℃)	+2%
High	4.6 °F (2.6 ℃)	+9%

2080	Temperature	Precipitation
Low	2.9 °F (1.6 ℃)	-2%
Medium	5.6 °F (3.1 ℃)	+6%
High	8.8 °F (4.9 ℃)	+18%

[1] Scenarios of future climate for the Pacific Northwest, 2005, Mote, P., E. Salathe, C. Peacock



Pacific Northwest

Precipitation

"Projected precipitation changes are modest, and are unlikely to be distinguishable from natural variability until late in the 21st century."[1]

"Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation)."[2]

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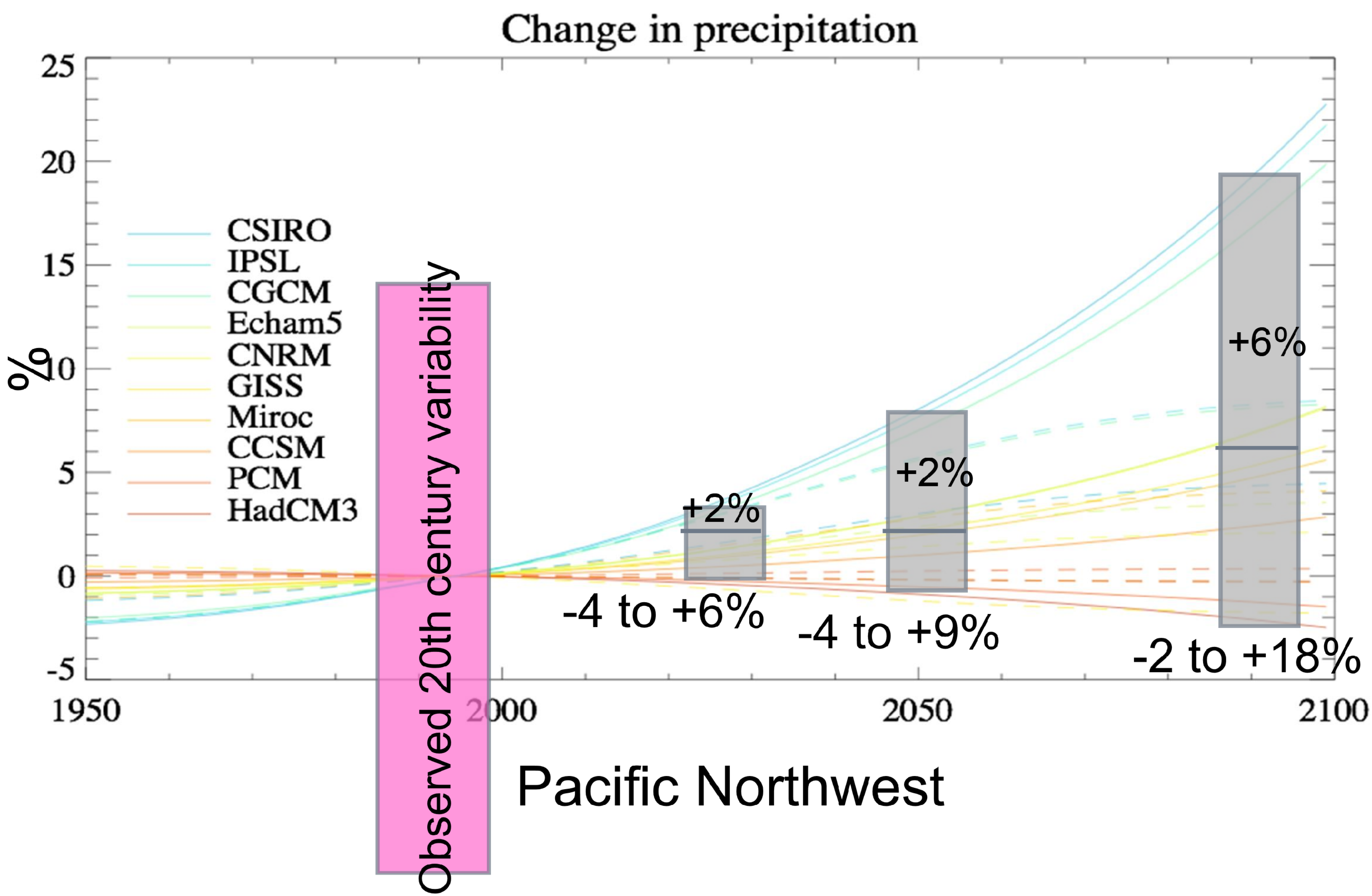
2 IPCC Fourth Assessment Report, Synthesis Report. 2007



Change in precipitation
%
25
20
15
10
5
0
-5
1950
2000
2050
2100
CSIRO
IPSL
CGCM
Echam5
CNRM
GISS
Miroc
CCSM
PCM
HadCM3
Observed 20th century variability
+2%
-4 to +6%
+2%
-4 to +9%
+6%
-2 to +18%
Pacific Northwest

Assumptions and Modeling

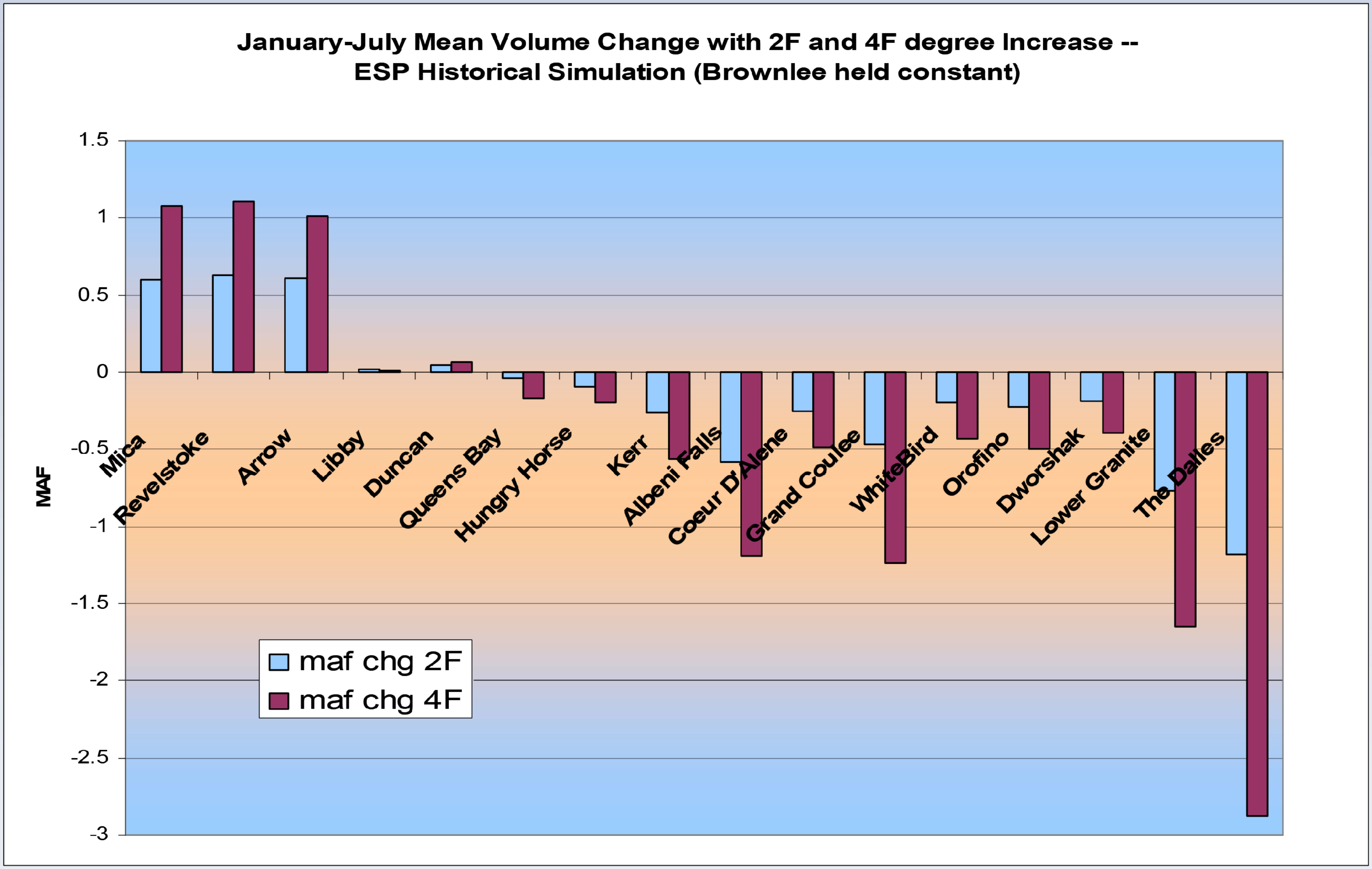
Streamflow Modeling

- +2 °F (1.1 C)
- +4 °F
- No diurnal shaping
- No precipitation adjustment
- Continuous 44 years (1950-1993)
- NWSRFS

Assumptions and Modeling (cont.)

Operational Modeling

- Rule curves (i.e. flood control, Variable Energy Content Curves) developed from perfect knowledge of volumes and runoff
- Monthly time-steps
- No load adjustment
- Hydsim regulation model



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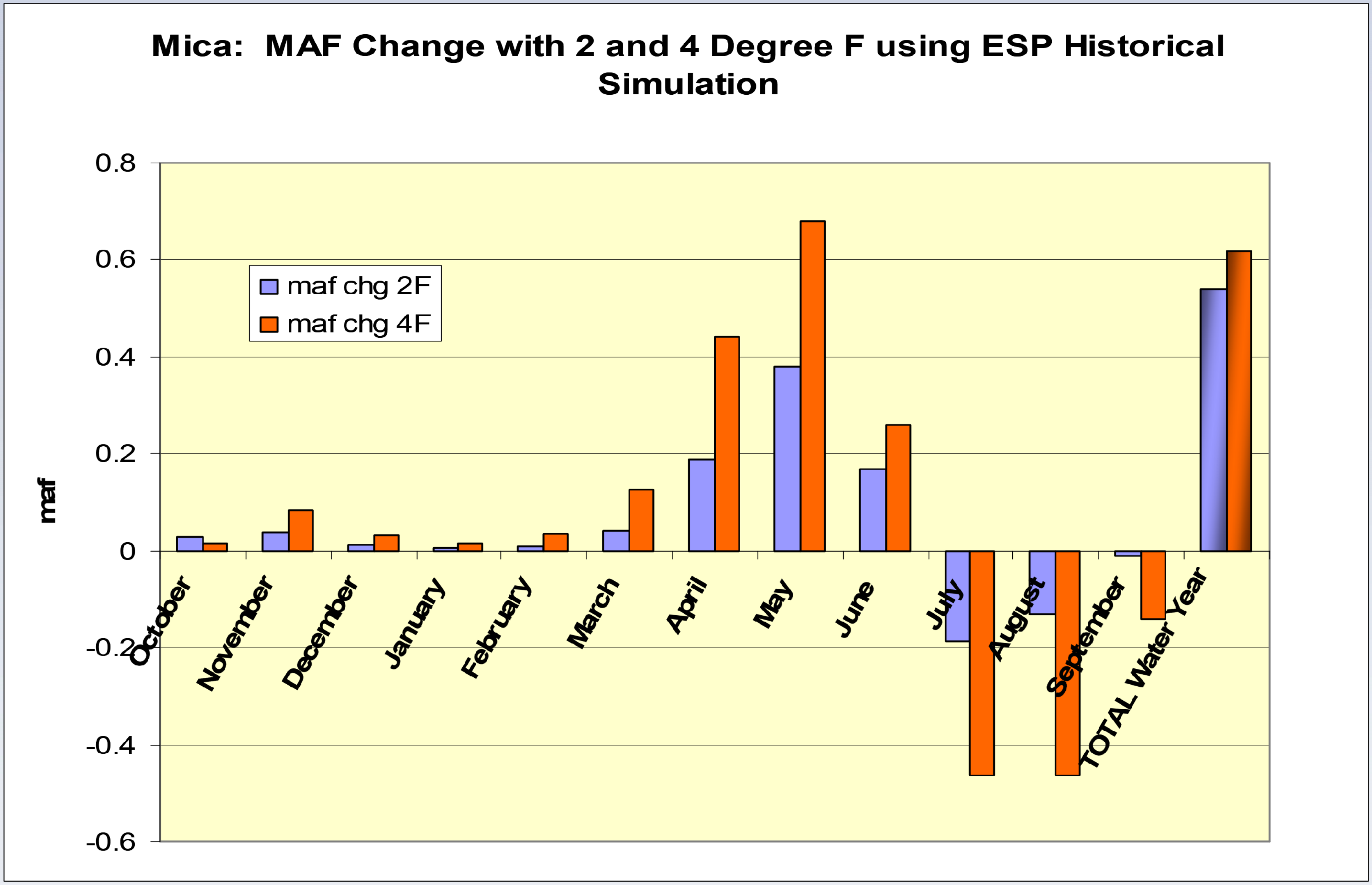
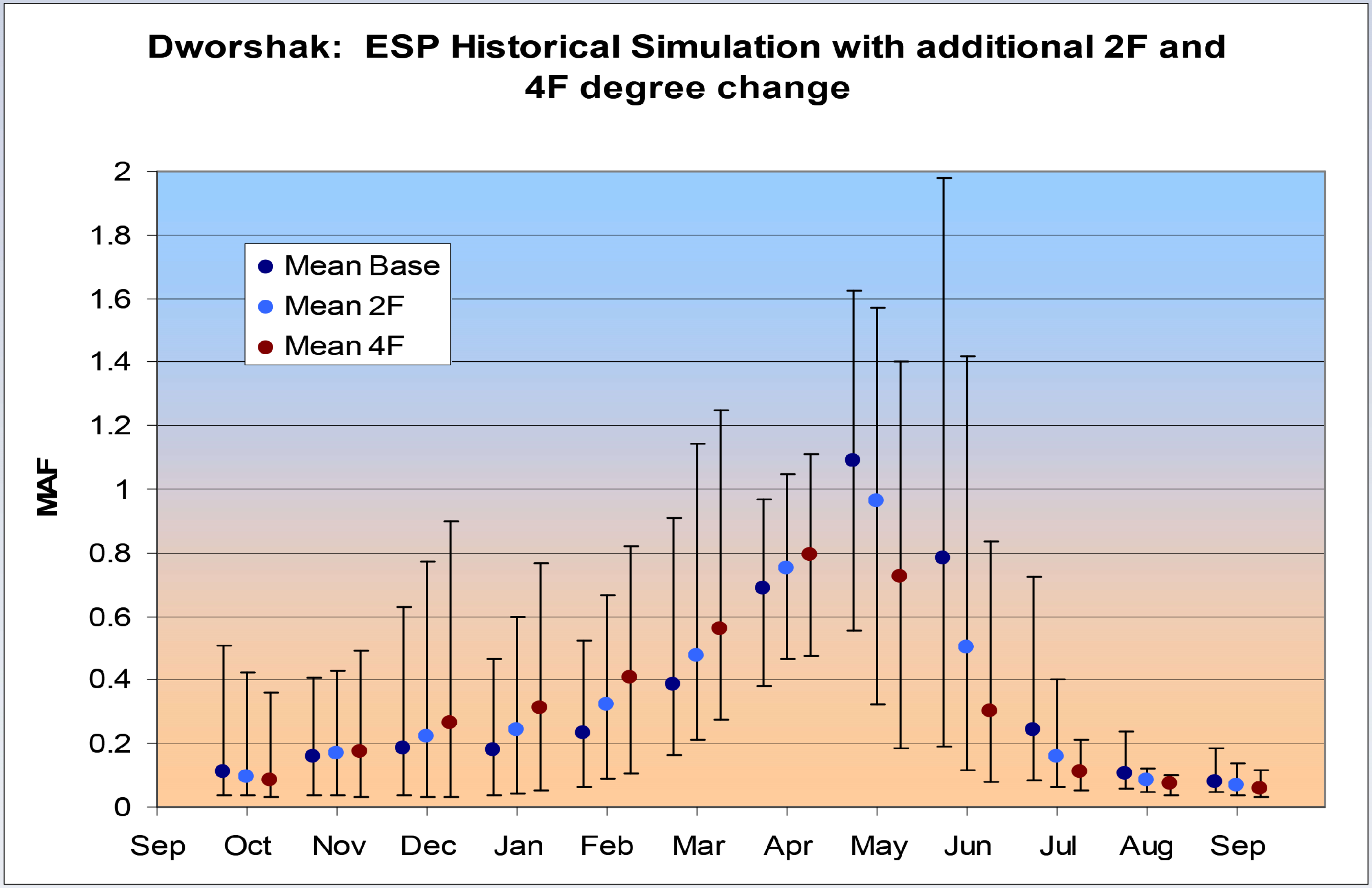
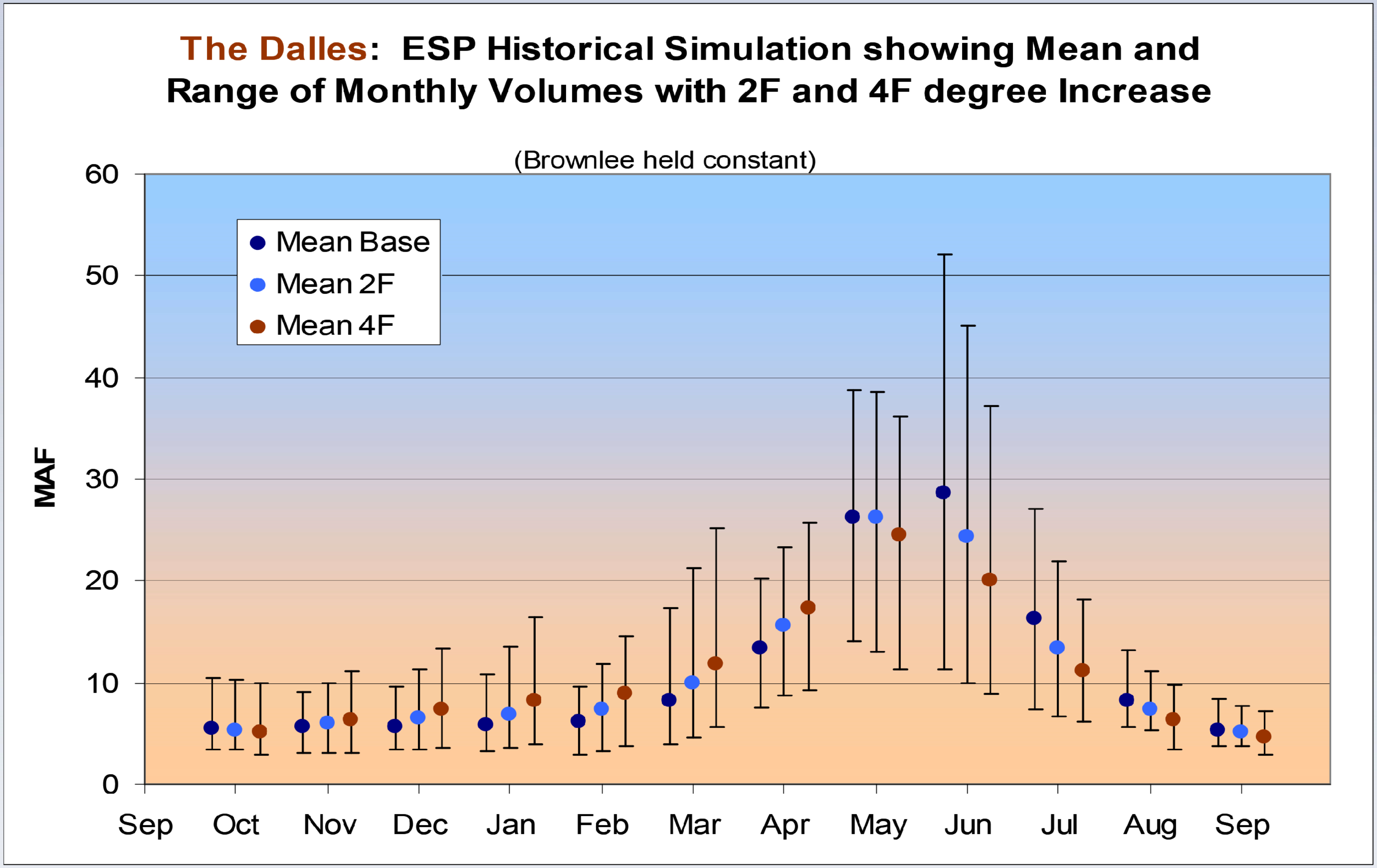
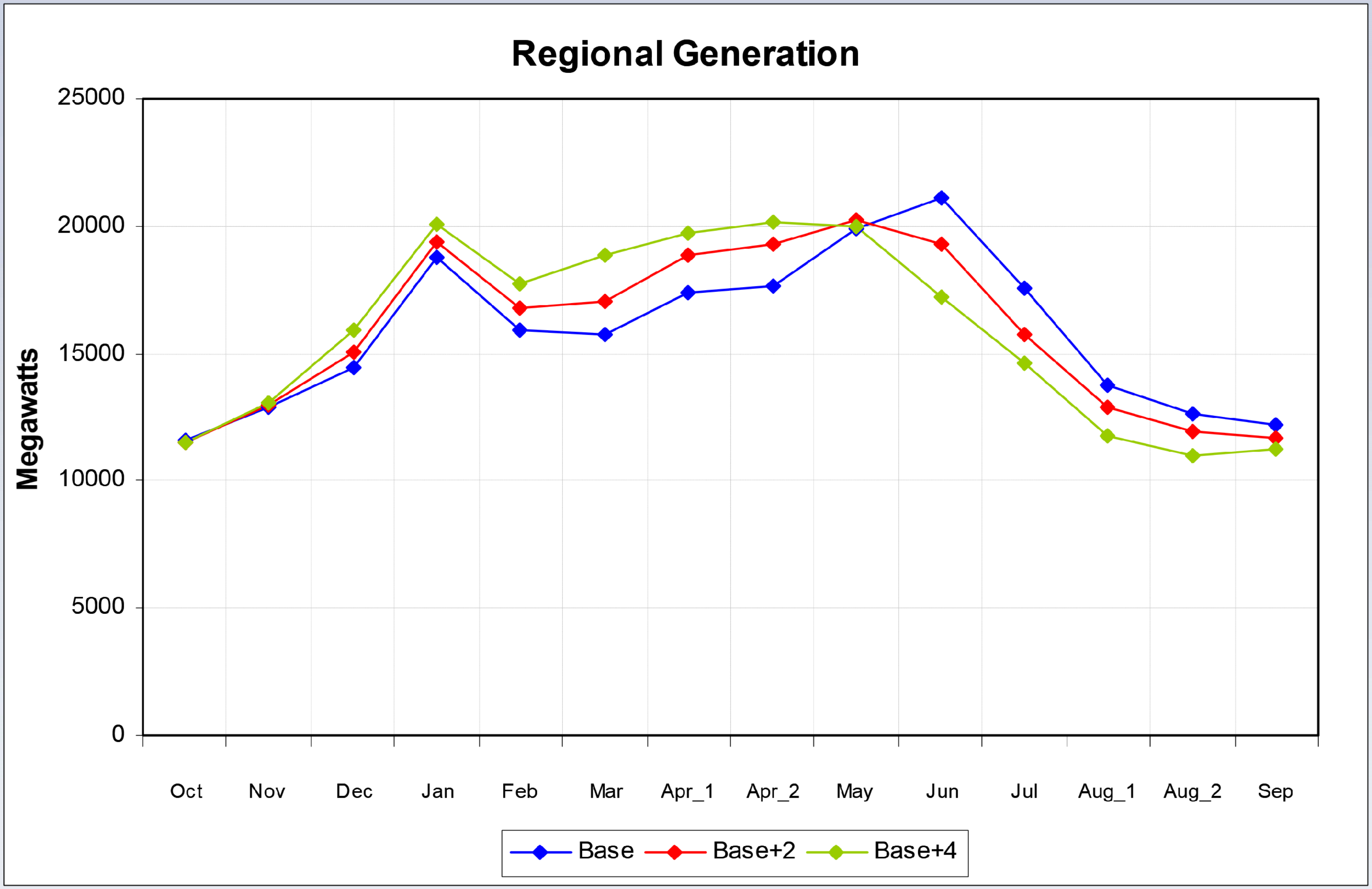


Mica: MAF Change with 2 and 4 Degree F using ESP Historical Simulation
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
maf
maf chg 2F
maf chg 4F
October
November
December
January
February
March
April
May
June
July
August
September
TOTAL Water Year


Dworshak: ESP Historical Simulation with additional 2F and 4F degree change
MAF
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mean Base
Mean 2F
Mean 4F
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep


The Dalles: ESP Historical Simulation showing Mean and Range of Monthly Volumes with 2F and 4F degree Increase
(Brownlee held constant)
MAF
60
50
40
30
20
10
0
Mean Base
Mean 2F
Mean 4F
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep



Regional Generation
Megawatts
25000
20000
15000
10000
5000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr_1
Apr_2
May
Jun
Jul
Aug_1
Aug_2
Sep
Base
Base+2
Base+4

Next Steps

- Work with the NPCC Genesys model to regulate
- Select cases to evaluate
- Develop rule curves for cases
- Adjust loads for temperature
- Adjust for future load/resource changes
- Develop scenarios with Hydsim

Bonneville Power Administration Climate Change Modeling Efforts

Nancy Stephan

RMJOC Climate Change Workshop

May 6th, 2008

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A2 and B1 Scenarios **x** 10 GCM Models **x** 2020 2050 2080

= 60 Sets

16^{th} degree resolution

200 Sites

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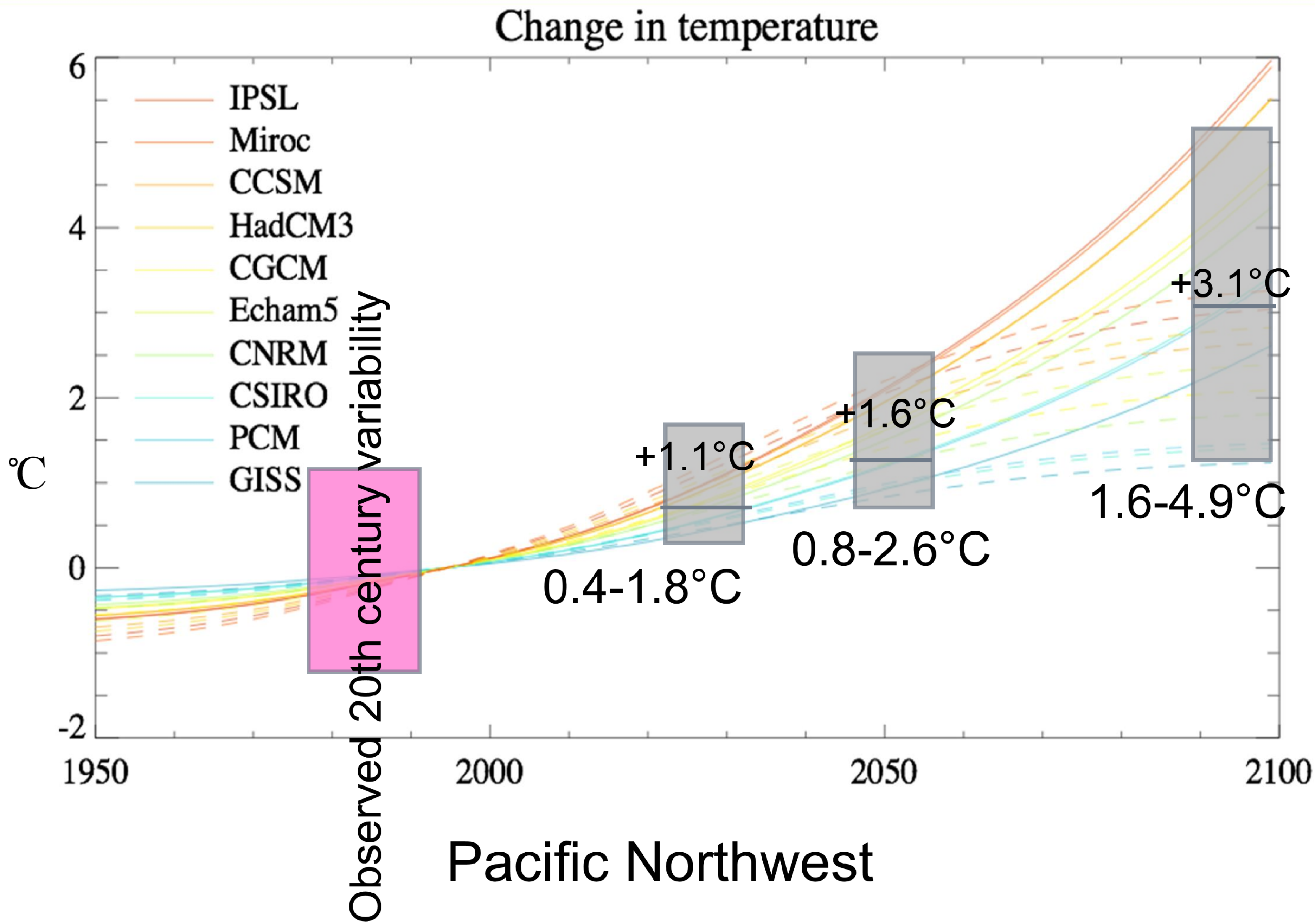
Change in temperature
IPSL
Miroc
CCSM
HadCM3
CGCM
Echam5
CNRM
CSIRO
PCM
GISS
℃
6
4
2
0
-2
1950
2000
2050
2100
Observed 20th century variability
+1.1°C
0.4-1.8°C
+1.6°C
0.8-2.6°C
+3.1°C
1.6-4.9°C
Pacific Northwest

Precipitation

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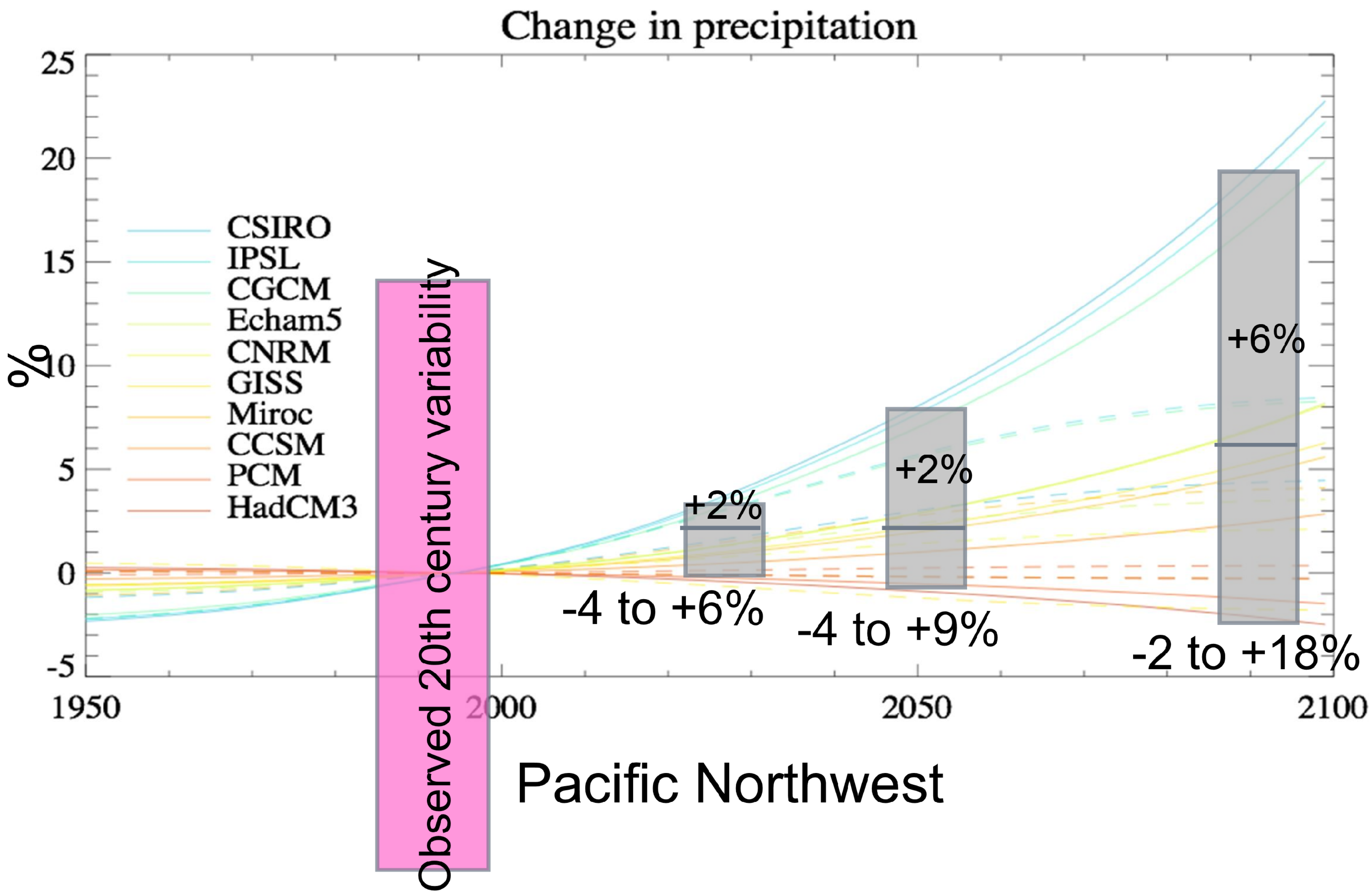
Change in precipitation
25
20
15
10
5
0
-5
%
1950
2000
2050
2100
CSIRO
IPSL
CGCM
Echam5
CNRM
GISS
Miroc
CCSM
PCM
HadCM3
Observed 20th century variability
+2%
-4 to +6%
+2%
-4 to +9%
+6%
-2 to +18%
Pacific Northwest

Assumptions and Modeling

Streamflow Modeling

- +2 °F
- +4 °F
- No diurnal shaping
- No precipitation adjustment
- Continuous 44 years (1950-1993)
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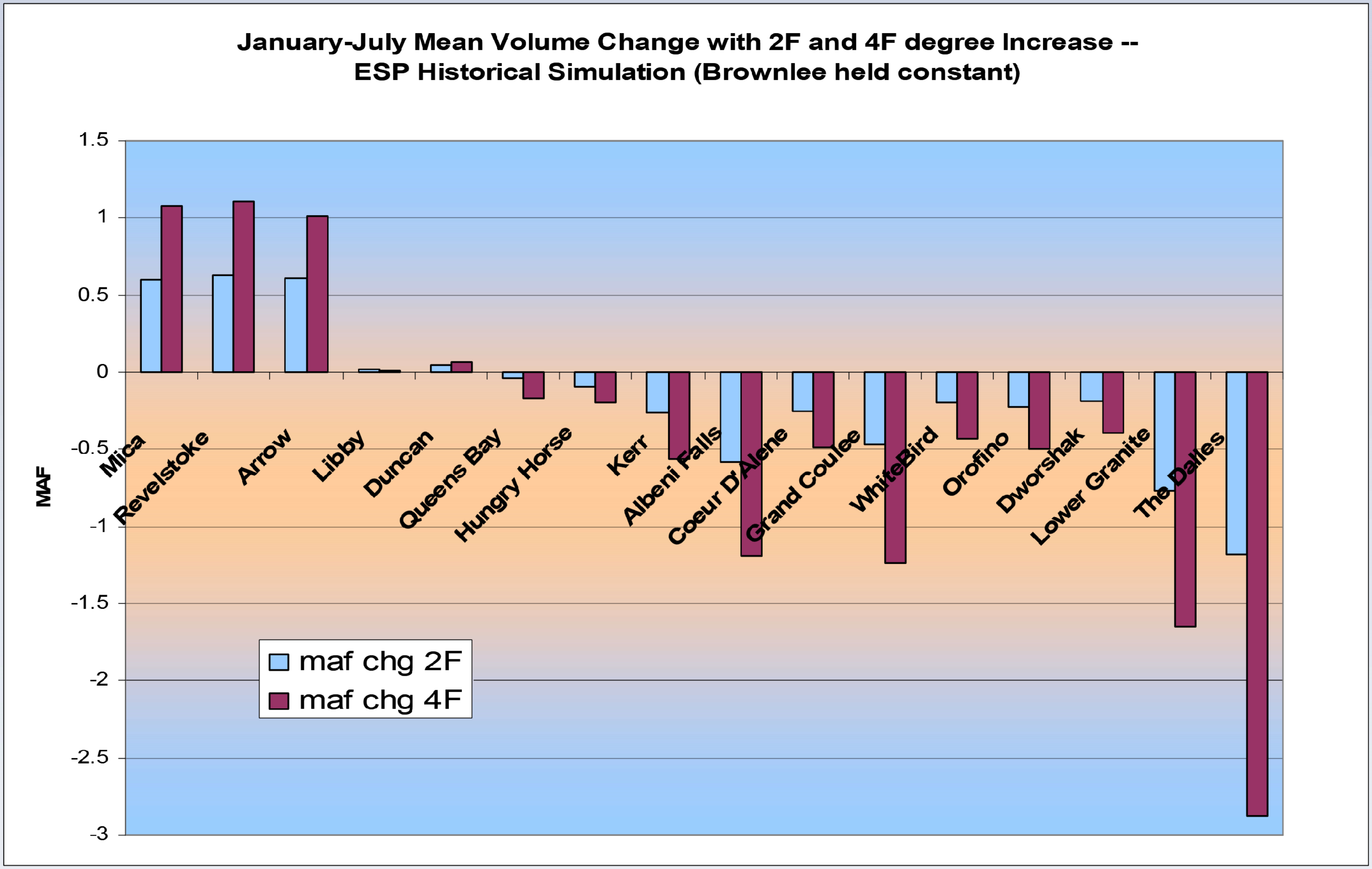
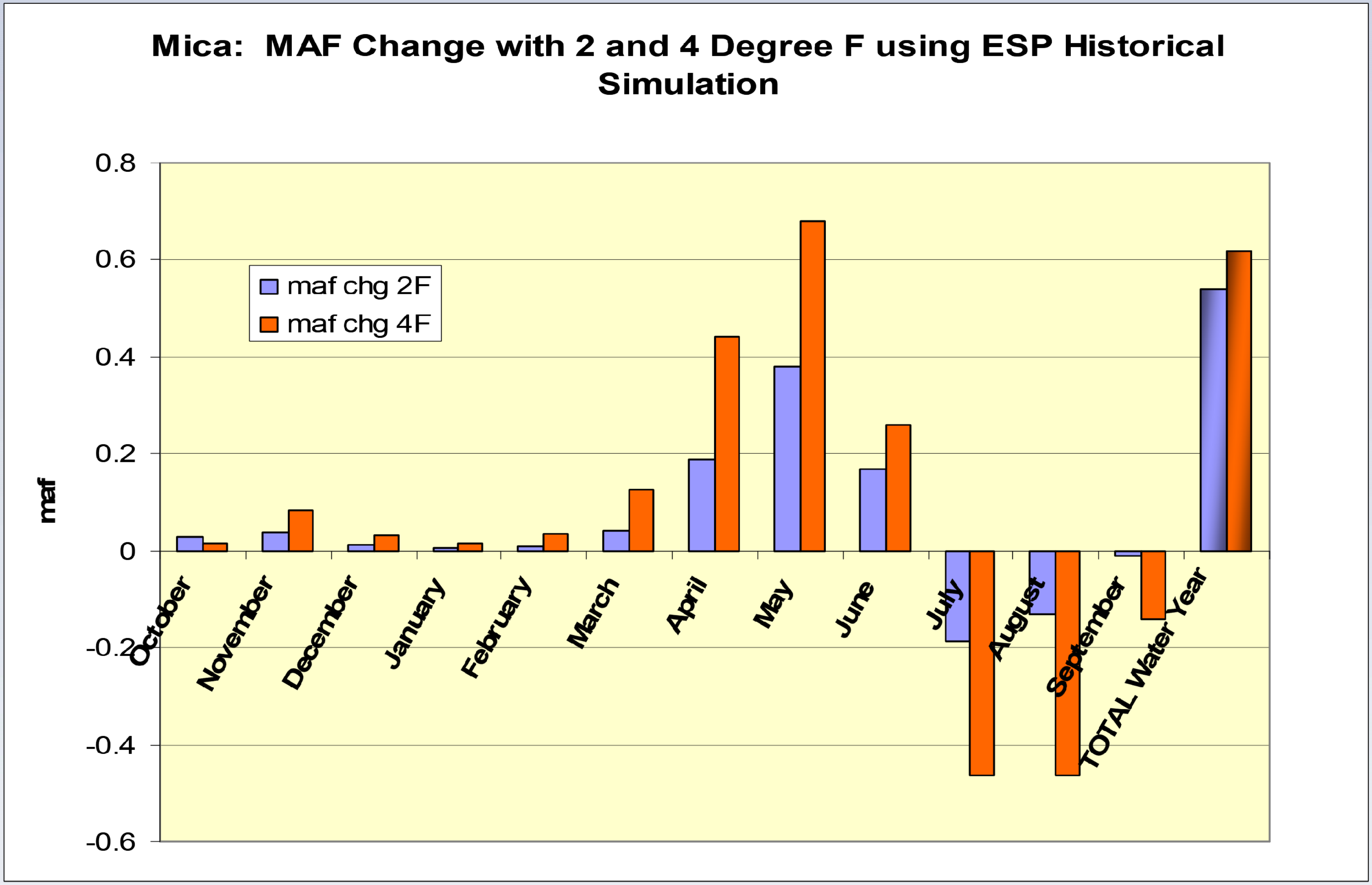
Assumptions and Modeling (cont.)

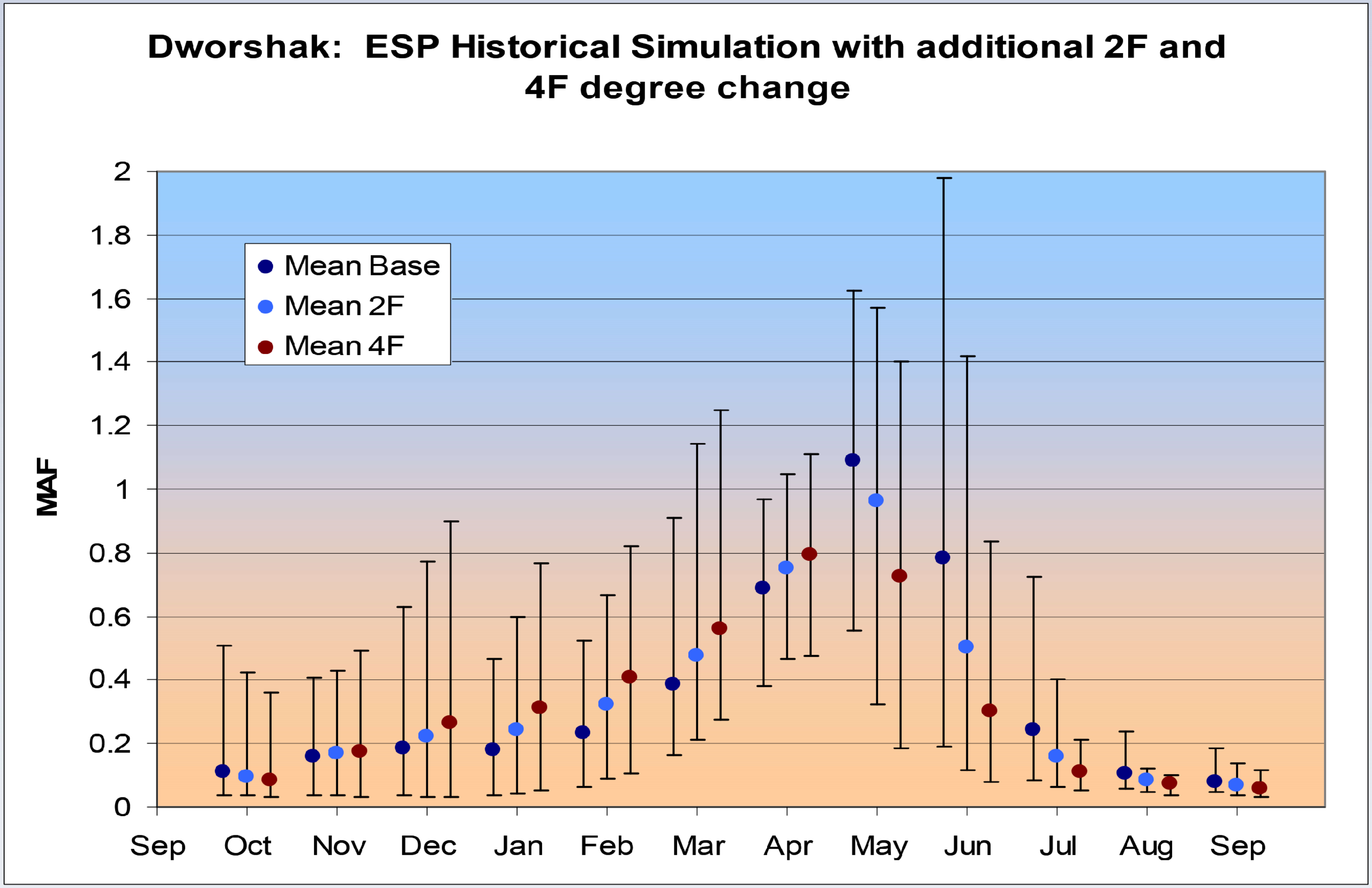
Operational Modeling

- Rule curves (i.e. flood control, Variable Energy Content Curves) developed from perfect knowledge of volumes and runoff
- Monthly time-steps
- No load adjustment
- Hydsim regulation model

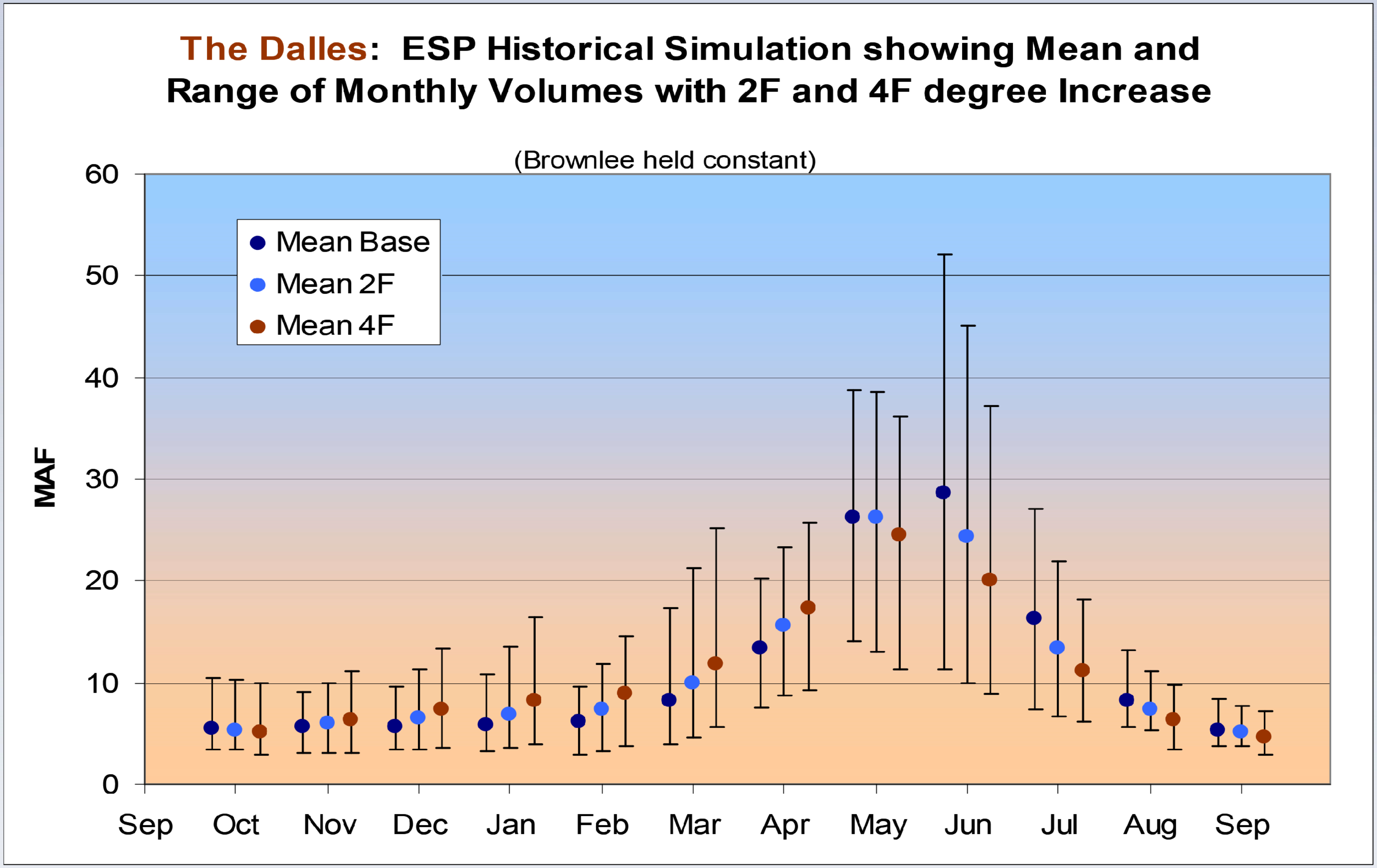

January-July Mean Volume Change with 2F and 4F degree Increase --
ESP Historical Simulation (Brownlee held constant)
MAF
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
Mica
Revelstoke
Arrow
Libby
Duncan
Queens Bay
Hungry Horse
Kerr
Albeni Falls
Coeur D'Alene
Grand Coulee
WhiteBird
Orofino
Dworshak
Lower Granite
The Dalles
maf chg 2F
maf chg 4F

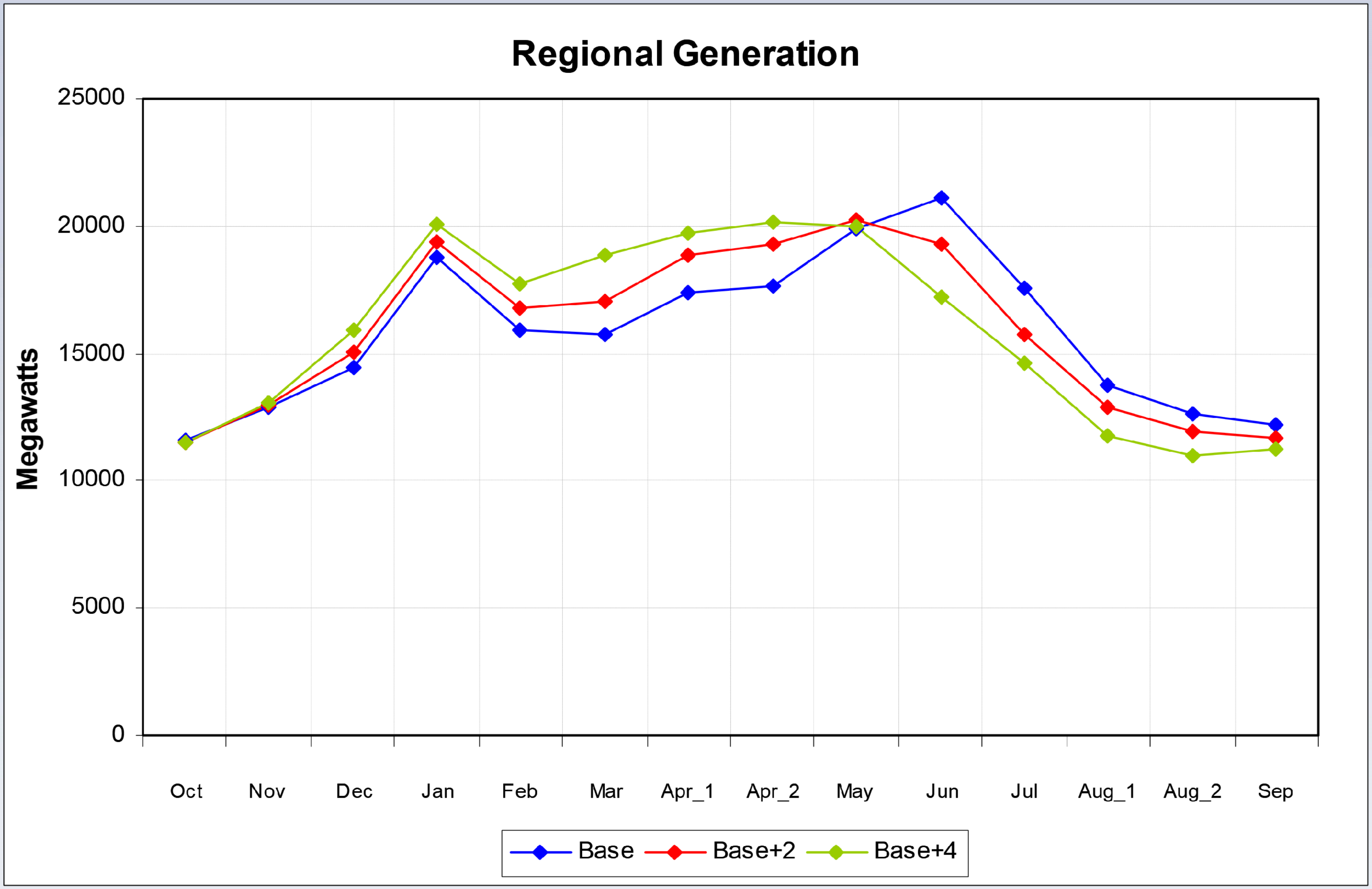


Mica: MAF Change with 2 and 4 Degree F using ESP Historical Simulation
maf chg 2F
maf chg 4F
maf
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
October
November
December
January
February
March
April
May
June
July
August
September
TOTAL Water Year



Dworshak: ESP Historical Simulation with additional 2F and 4F degree change
Mean Base
Mean 2F
Mean 4F
MAF
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep


The Dalles: ESP Historical Simulation showing Mean and Range of Monthly Volumes with 2F and 4F degree Increase
(Brownlee held constant)
MAF
60
50
40
30
20
10
0
Mean Base
Mean 2F
Mean 4F
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep


Regional Generation
Megawatts
25000
20000
15000
10000
5000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr_1
Apr_2
May
Jun
Jul
Aug_1
Aug_2
Sep
Base
Base+2
Base+4

Next Steps

- Work with the NPCC Genesys model to regulate
- Select cases to evaluate
- Develop rule curves for cases
- Adjust loads for temperature
- Adjust for future load/resource changes
- Develop scenarios with Hydsim

Predicting the hydrologic response of the Columbia River system to climate change

Task 2. Acquisition of climate model data: Selection and acquisition of CMIP5 and NARCCAP model output for individual RCPs and emission scenarios in consultation with the RMJOC

26 March 2014

Prepared for the

Bonneville Power Administration

by

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Executive summary

From the available pool of climate projections from the Coupled Model Intercomparison Project phase 5 (CMIP5), a preliminary recommendation was made of 20 climate simulations that will provide the basis for the meteorological inputs to hydrological models of the Columbia Basin. The 20 climate simulations come from 10 global climate models (GCMs) and 2 Representative Concentration Pathways (RCPs). The 2 RCPs represent greenhouse gas emissions assuming moderate mitigation steps throughout the 21st century (RCP4.5) and a "business as usual" scenario (RCP8.5). The selection of the GCMs considered the ability of the models to reproduce the 20th century climate of the Pacific Northwest USA, balanced by a desire to adequately sample the distribution of climate projections from the full set of CMIP5 GCMs. The recommended 10 GCMs are listed in Table 1.

Table 1. CMIP5 GCMs used to generate selected climate scenarios

CCSM4
CNRM-CM5
HadGEM2-ES
CanESM2
IPSL-CM5A-MR
bcc-csm1-1-m
MIROC5
NorESM1-M
CSIRO-Mk3-6-0
inmcm4

1. Climate Model Data

Monthly time series of temperature and precipitation simulated for the 20th and 21st centuries were acquired from 32 global climate models (GCMs) included in the Coupled Model Intercomparison Project phase 5 (CMIP5) (see Table A1). The simulations for the historical period (1900-2005) were driven by observed greenhouse gas (GHG) and aerosol concentrations, whereas simulations for the future period (2006-2100) were driven by projections of GHG and aerosol concentrations as specified in the Representative Concentration Pathways (RCPs) 4.5 and 8.5. In some cases, more than 1 simulation was available per GCM and RCP. In such cases, the multiple simulations differed only by their initial conditions (i.e., state of atmosphere/ocean at time = 0) and are referred to as an *ensemble*.

Time series of temperature and precipitation were also acquired from the regional climate models (RCMs) used in the North American Region Climate Change Assessment Project (NARCCAP). NARCCAP ran RCMs (50 km resolution) of North America nested within GCMs. 5 regional climate models were coupled to 4 global climate models (see Table A2), though not all possible global-regional model combinations were employed. Data is available for 10 combinations of RCM-GCMs (see Table A3). Unlike CMIP5, NARCCAP is limited to time slices during the 20th and 21st centuries. The common periods across models are 1968-1999 and 2038-2069. The future period was forced by projections of GHG and aerosol concentrations as specified by the scenario known as the Special Report on Emissions Scenarios (SRES) A2.

The total radiative forcing above pre-industrial levels is given in Fig. 1 for SRES A2, RCP 4.5 and RCP 8.5. Note that SRES A2 lies between RCP 4.5 and RCP 8.5 during the first half of the 21st century, in terms of total radiative forcing. By 2050, SRES A2 and RCP 4.5 are similar, but they deviate sharply during the latter half of the 21st century.

2. Climate Scenario Selection

The objective of Task 2 of this project was to select 20 climate scenarios from the available pool of CMIP5-based climate projections. The 20 scenarios were to source from 10 GCMs and 2 RCPs (4.5 and 8.5). RCP 4.5 and RCP 8.5 were chosen because they provided the largest number of simulations from all the modeling groups. The other 2 RCPs (2.6 and 6.0) had few simulations available; moreover, RCP2.6 is considered to be unlikely. The selection of climate scenarios from the full database of CMIP5 GCM simulations was based on 3 criteria:

A) Availability of downscaled GCM simulations using MACA methodology
B) Historical model performance
C) Projections of mean temperature and precipitation changes

Criterion A is motivated by a primary objective of this project: to drive a hydrological model with statistically downscaled simulations from GCMs. The chosen method of downscaling is the Multivariate Adaptive Constructed Analogs (MACA: Abatzoglou and Brown, 2011; http://nimbus.cos.uidaho.edu/MACA/). Five meteorological variables were downscaled using MACA at the daily frequency to a horizontal resolution of 1/16 degree (~6 km). The variables are maximum and minimum daily air temperature, precipitation total, mean daily incoming surface shortwave radiation, mean wind speed, and mean specific humidity. Of the total number of CMIP5

GCMs available, only 20 offered all of these variables at the daily frequency for RCP4.5 and RCP8.5. Criterion A, therefore, reduced the total number of available GCMs to 20. These 20 GCMs are listed in Table 2.

Table 2. Available downscaled global climate simulations by CMIP5 GCM[1] using MACA, 1950-2100, RCP4.5 and RCP8.5

BCC-CSM1-1
BCC-CSM1-1-M
BNU-ESM
CanESM2
CCSM4
CNRM-CM5
CSIRO-Mk3-6-0
GFDL-ESM2G
GFDL-ESM2M
HadGEM2-CC
HadGEM2-ES
INMCM4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MRI-CGCM3
NorESM1-M

[1]First ensemble member only, where more than one member provided.

The second selection criterion (B) was to give preference to those GCMs that were shown to better reproduce properties of the historical climate of the Pacific Northwest USA (PNW). The performance evaluation methodology and results are given in Section 2.1 below.

The third criterion (C) was to sample the range of projected changes in mean temperature and precipitation over the Columbia Basin as given by CMIP5 GCMs under RCP4.5 and RCP8.5. The projected changes are described in Section 2.2 below.

2.1. Model Performance

The CMIP5 GCMs were evaluated and ranked based on their ability to reproduce certain statistical properties of the observed 20th century climate of the PNW and surrounding region. The methodology and results are described in detail in Rupp et al. (2013); here we provide merely a brief summary.

Rupp et al. (2013) relied on 18 performance metrics, which are listed in Table 3. The relative error for each of the 32 GCMs by metric is show in Fig. 2. Note that though relative error ranges from 0 to 1, a value of 0 does not mean the model had no error, but that it was the model with the least error of the 32 models for that metric.

Dependencies (i.e. correlations) between metrics indicate a degree of redundancy among metrics. To account for this redundancy, Rupp et al. (2013) conducted an empirical orthogonal function (EOF; also know as principle components) analysis on the 18 metrics. The EOF analysis is one objective method of weighting metrics and allowed for the reduction of a large number of metrics to a much smaller number that still accounted for the majority of the variability in the models' performance. The final ranking based on the EOF analysis is shown by the ordering of the models in each of Figs. 3-12. This ranking differs slightly, but not markedly, from the ordering in Fig. 2, which treated each metric with equal weight.

2.2. Model Projections

Changes in 30-year mean annual and seasonal temperature and precipitation were calculated from a baseline period of 1970-1999 to two future periods: 2030-2069 and 2040-69. The first period, referred to as the "2040s", is consistent with that used by the RMJOC in previous studies. The second period, the "2050s", was included so the CMIP5 and NARCCAP projections could be compared.

Seasons were defined as winter (December – February, DJF), spring (March - May, MAM), summer (June – August, JJA) and fall (September – November, SON).

Changes in temperature and precipitation, calculated as Columbia basin-wide averages, are shown for annual and seasonal values in Figs. 3 – 12.

NARCCAP-projected changes in temperature and precipitation relative to CMIP5 for the 2050's are show in Fig. 13. Not unexpectedly, NARCCAP projections fall within the cloud of CMIP5 projections for RCP4.5 as both SRES A2 and RCP 4.5 provide similar levels of radiative forcing by mid-21st century. Note that there is more variability in precipitation projections among GCMs than among RCMs across the NARCCAP RCM-GCM combinations.

2.3. Selected Climate Scenarios

As stated above, limiting ourselves to the MACA dataset eliminated 12 of the GCMs from the 32 evaluated in this study. Moreover, for those GCMs with more than one ensemble member, the MACA dataset contains only the first member. This restricted us from selecting other ensemble members from a GCM that may provide a broader range in projections in either temperature or precipitation (see, for example, CanESM2, model #8, RCP 8.5 in Fig. 3).

Table 3. Performance metrics used in GCM ranking for the Pacific Northwest USA[1]

Metric	Description
Mean-T	Mean annual temperature (T), 1960-1999
Mean-P	Mean annual precipitation (P), 1960-1999
SeasonAmp-T	Mean amplitude of T seasonal cycle as difference between warmest and coolest month, 1960-1999
SeasonAmp-P	Mean amplitude of P seasonal cycle as difference between wettest and dryest month, as percentage of mean annual total P, 1960-1999
Trend-T	Linear trend in annual T, 1901-1999
ENSO-T	Correlation of winter T with Nino3.4 index, 1901-1999
TimeVar.1-T	Variance of annual T, 1901-1999
TimCV.1-P	Coefficient of variation of water year P, 1902-1999
DTR-DJF	Mean diurnal temperature range in winter, 1950-1999
DTR-JJA	Mean diurnal temperature range in summer, 1950-1999
SpaceCor-DJF-T[2]	Correlation of simulated with observed spatial pattern in mean winter T, 1960-1999
SpaceCor-JJA-T[2]	Correlation of simulated with observed spatial pattern in mean summer T, 1960-1999
SpaceCor-DJF-P[2]	Correlation of simulated with observed spatial pattern in mean winter P, 1960-1999
SpaceCor-JJA-P[2]	Correlation of simulated with observed spatial pattern in mean summer P, 1960-1999
SpaceSD-DJF-T[2]	Standard deviation of spatial pattern in mean winter T, 1960-1999
SpaceSD-JJA-T[2]	Standard deviation of spatial pattern in mean summer T, 1960-1999
SpaceSD-DJF-P[2]	Standard deviation of spatial pattern in mean winter P, 1960-1999
SpaceSD-JJA-P[2]	Standard deviation of spatial pattern in mean summer P, 1960-1999

[1]Domain: 124.5°W – 110.5°W, 41.5°N – 49.5°N

[2]Metric calculated over expanded domain: 165°W - 100°W, 20°N - 60°N

In an initial sweep through the projections, we selected the 10 GCMs that were both i) ranked highest by Rupp et al. (2013) and ii) had been downscaled using the MACA methodology. These 10 GCMs ranged from CCSM5 (#3) to IPSL-CM5A-LR (#15); ranking given in parentheses. Including both RCPs, this selection of 20 scenarios sampled both the central and high projections in temperature change, with respect to annual (Figs. 3 and 8) and seasonal means (Figs. 4-7; 9-12). However, the "top ten" models under-sampled the lower end of the distribution of temperature changes. While this could imply that the lower estimates of warming are less reliable, there is no evidence as of yet that model performance as provided in Rupp et at. (2013) is a strong indicator of model reliability in future projections of the climate of the Columbia Basin.

Therefore, to include a model that gave less warming in the future, we substituted HadGEM2-CC (#5) with INMCM4 (#23). This final list of 10 recommended GCMs is given in Table 1. HadGEM2-CC was replaced because of its similarity with HadGEM2-ES in projections of temperature and precipitation and its historical performance. Using both models from the same HadGEM2 *genus* would be somewhat akin to selecting the same GCM twice.

INMCM4 was among the least warming of all available models in all seasons of the year. MRI-CGCM3 (#22) was another low warming candidate with a slightly higher overall ranking than INMCM4. However, we preferred INMCM4 because it scored better in terms of variability in temperature and precipitation from scales ranging from annual to decadal - climatic properties that are not corrected during the bias-correction stage in MACA.

The 10 recommended GCMs tend to under-sample the full spread of projections in terms of percent changes in precipitation. It needs to be kept in mind, however, that much of the spread in precipitation projections is due to internal model variability and not in response to anthropogenic forcing. Moreover, the GCMs are known to under-represent temporal variability in precipitation at decadal scales (see Fig. A11 in Rupp et al. 2013), so one should question relying on the spread in differences in mean simulated precipitation between a past and future period to adequately sample the true distribution of possible future mean precipitation. It may be more important for this selection that the recommended sample of GCMs do not give a mean precipitation change that is considerably different from the full set of models.

References

Abatzoglou, J.T., and T.J. Brown. 2011: A Comparison of Statistical Downscaling Methods Suited for Wildfire Applications. International Journal of Climatology, doi:10.1002/joc.2312.

Rupp, D. E., J. T. Abatzoglou, K. C. Hegewisch, and P. W. Mote. 2013: Evaluation of CMIP5 20th century climate simulations for the Pacific Northwest USA. Journal of Geophysical Research: Atmospheres (118), 10,884-10,906, doi:10.1002/jgrd.50843.

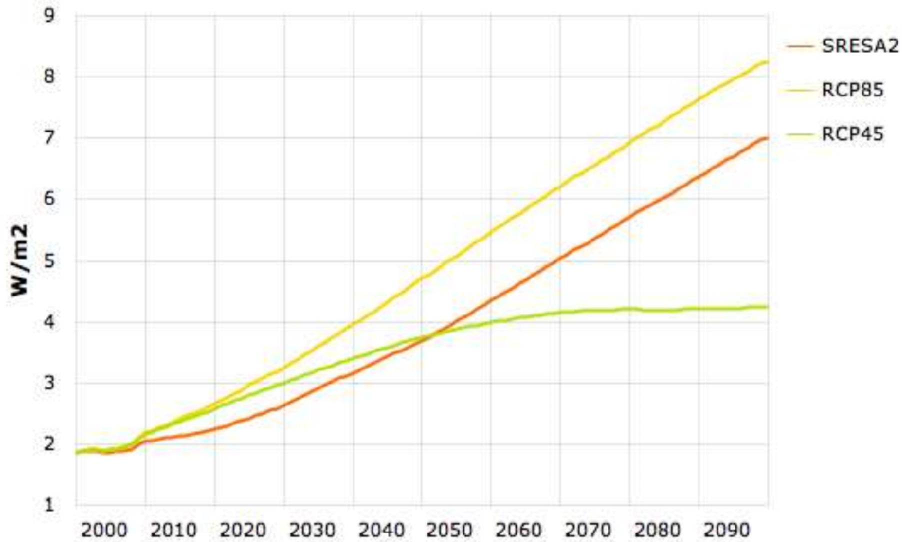


Figure 1. Total radiative forcing above pre-industrial levels for SRESA2, RCP4.5 and RCP8.5 during the 21st century (source: liveMAGICC).

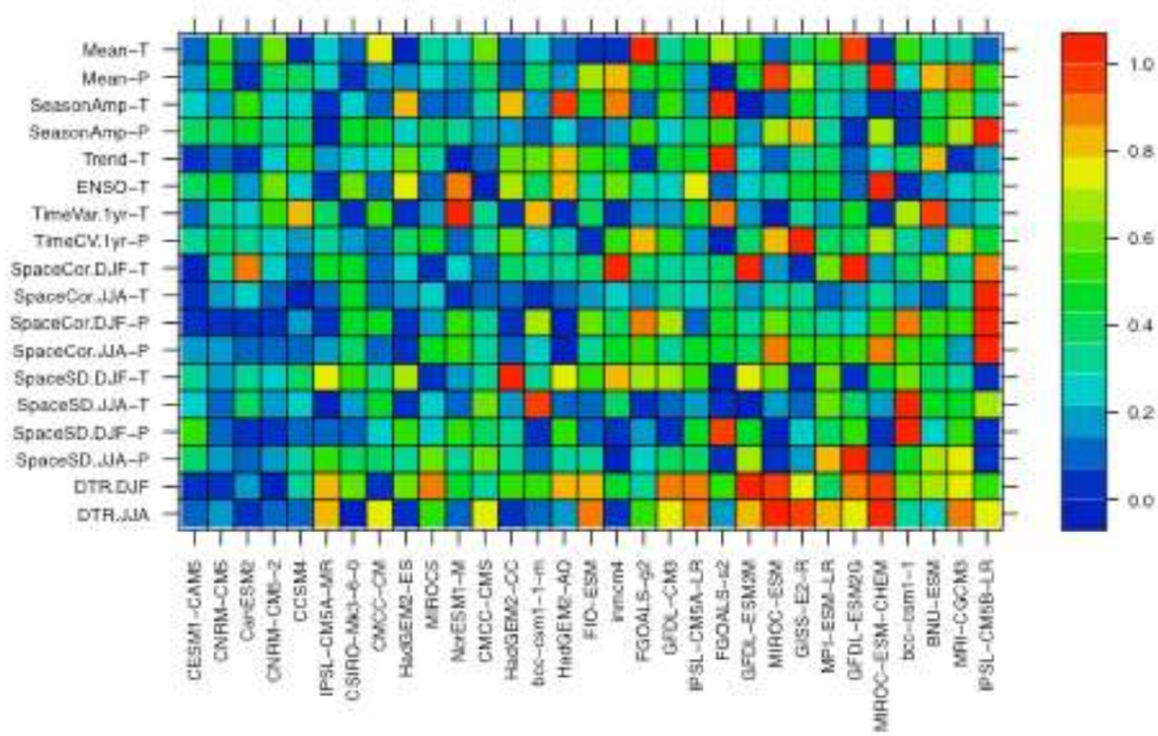


Figure 2. Relative error of the ensemble mean of each performance metric for each CMIP5 GCM. Models are ordered from least (left) to most (right) total relative error, where total relative error is the sum of relative errors from all metrics. Adapted from Rupp et al. (2013).

Extended caption to Figures 3 – 12.

Figures 3 through 12 below show projected changes in mean annual (or seasonal) temperature versus changes in mean annual (or seasonal) precipitation calculated as the difference from a 30-year long reference period to a 30-year long future period. Projections are from 32 CMIP5 GCMs under 2 scenarios of the future: RCP4.5 and RCP8.5. For some GCMs, multiple simulations with the same RCP are plotted. Table 3 lists the number of simulations, or ensemble members, for each GCM. The projections highlighted in bold color are the suggested 20 projections (10 GCMs times 2 RCPs) for serving as the source of the climate scenarios for this project.

The numbers in each plot correspond to the numbers in the list of GCMs to the right of each plot. The 20 GCMs listed in black have been statistically downscaled using the MACA method; those listed in gray have not. MACA downscaling has been done for only the first ensemble member for a given model for which more than one member is available.

The order of the GCMs in the list is based on a ranking (1 = best) of CMIP5 GCMs for the Pacific Northwest US in Rupp et al. (2013). Ranking was based on the ability of the GCMs to reproduce properties of the observed 20th century climate.

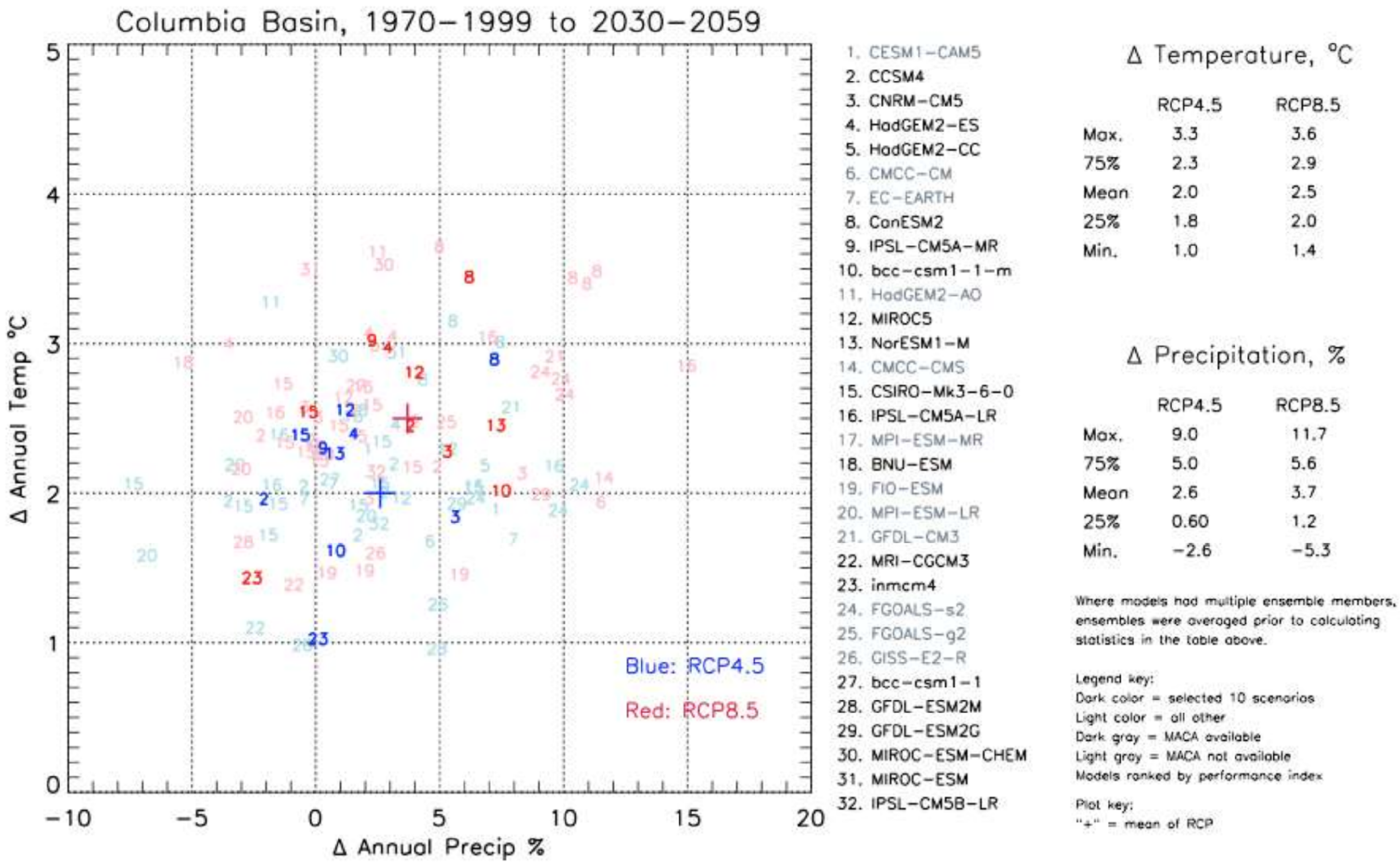
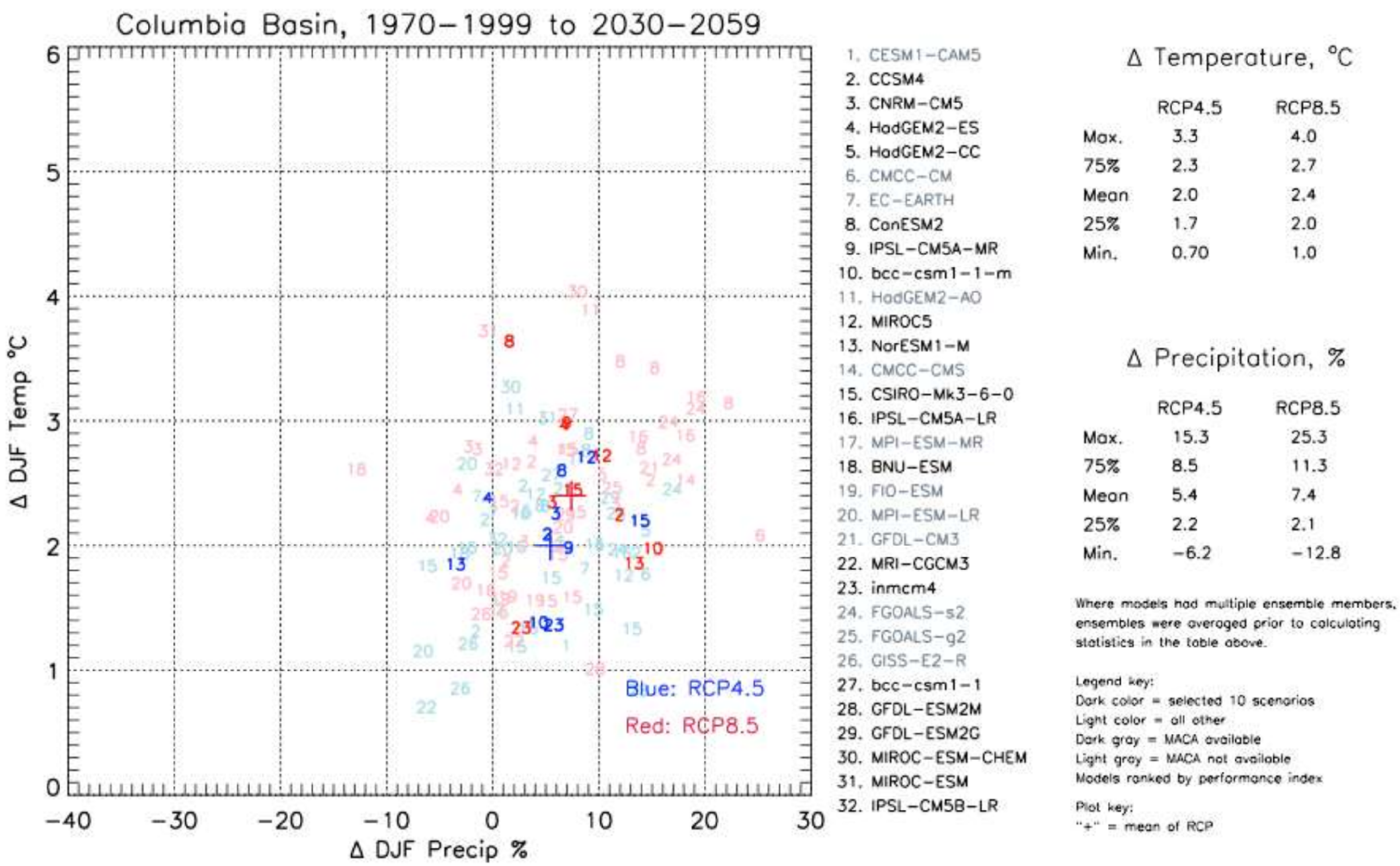


Figure 3. Projected changes in annual temperature and precipitation from CMIP5, 1970-1999 to 2030-2059. See complete figure description on page 10.



Δ Temperature, °C

	RCP4.5	RCP8.5
Max.	3.3	4.0
75%	2.3	2.7
Mean	2.0	2.4
25%	1.7	2.0
Min.	0.70	1.0

Δ Precipitation, %

	RCP4.5	RCP8.5
Max.	15.3	25.3
75%	8.5	11.3
Mean	5.4	7.4
25%	2.2	2.1
Min.	−6.2	−12.8

Figure 4. Projected changes in winter (DJF) temperature and precipitation from CMIP5, 1970-1999 to 2030-2059. See complete figure description on page 10.

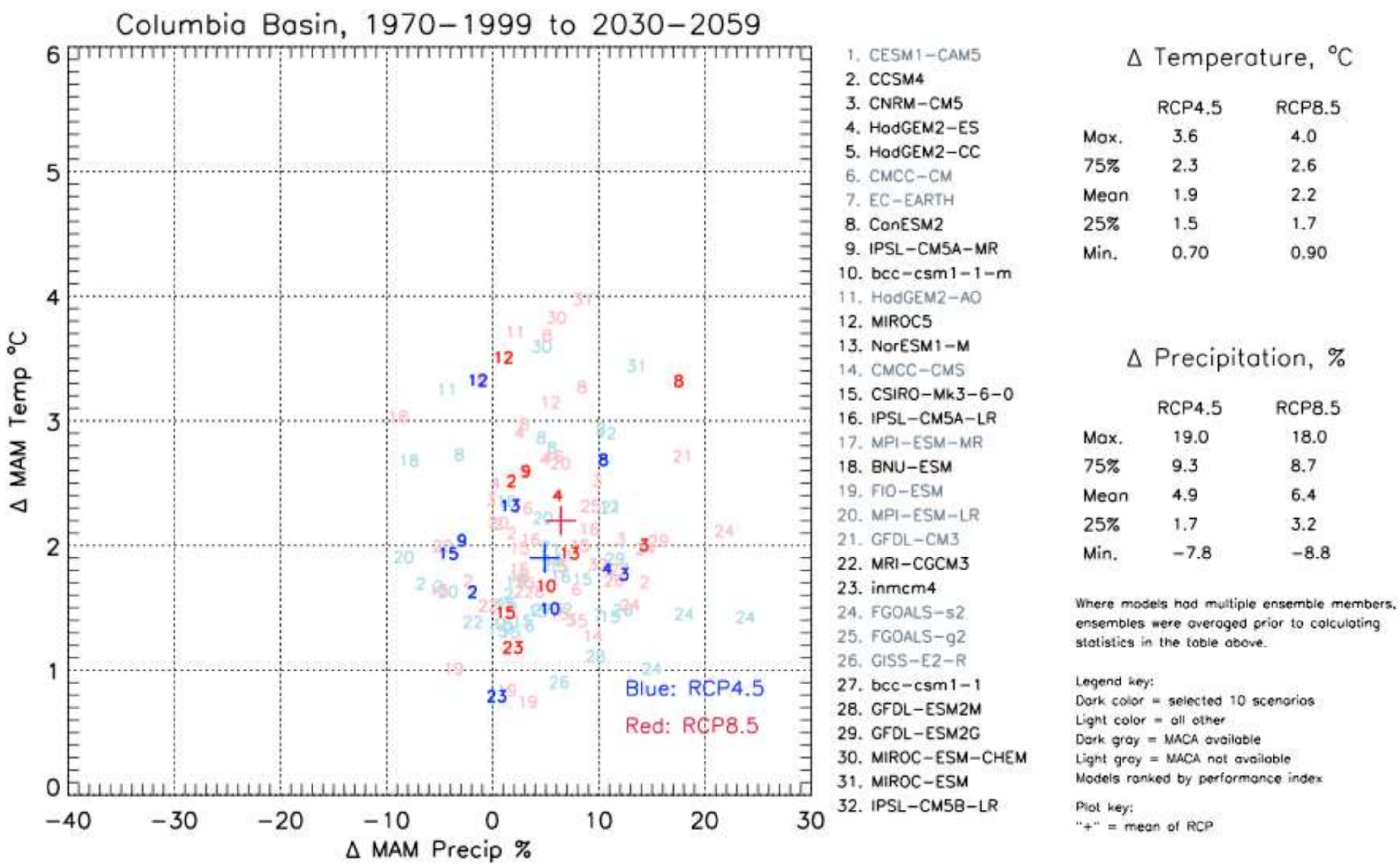


Figure 5. Projected changes in spring (MAM) temperature and precipitation from CMIP5, 1970-1999 to 2030-2059. See complete figure description on page 10.

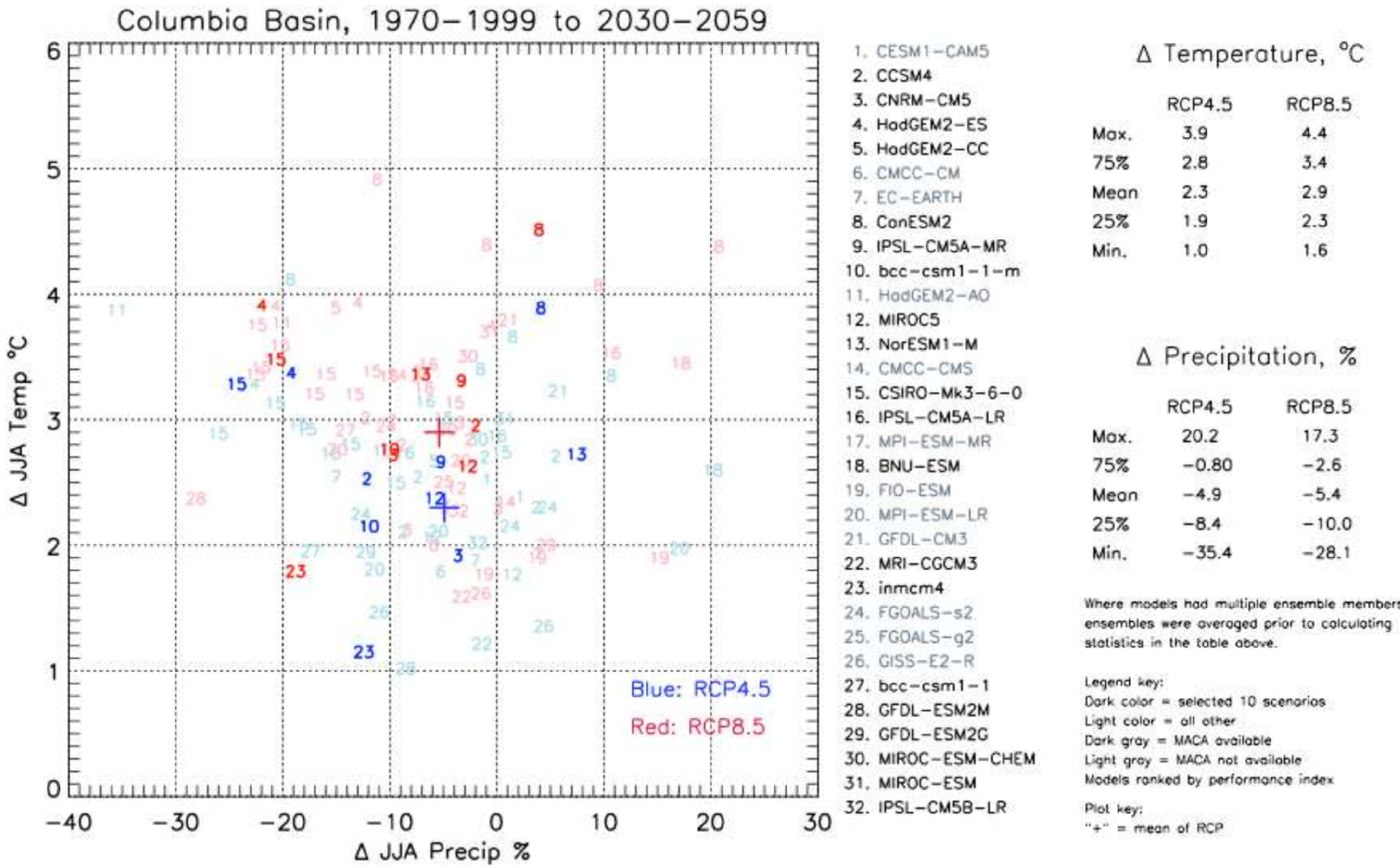


Figure 6. Projected changes in summer (JJA) temperature and precipitation from CMIP5, 1970-1999 to 2030-2059. See complete figure description on page 10.

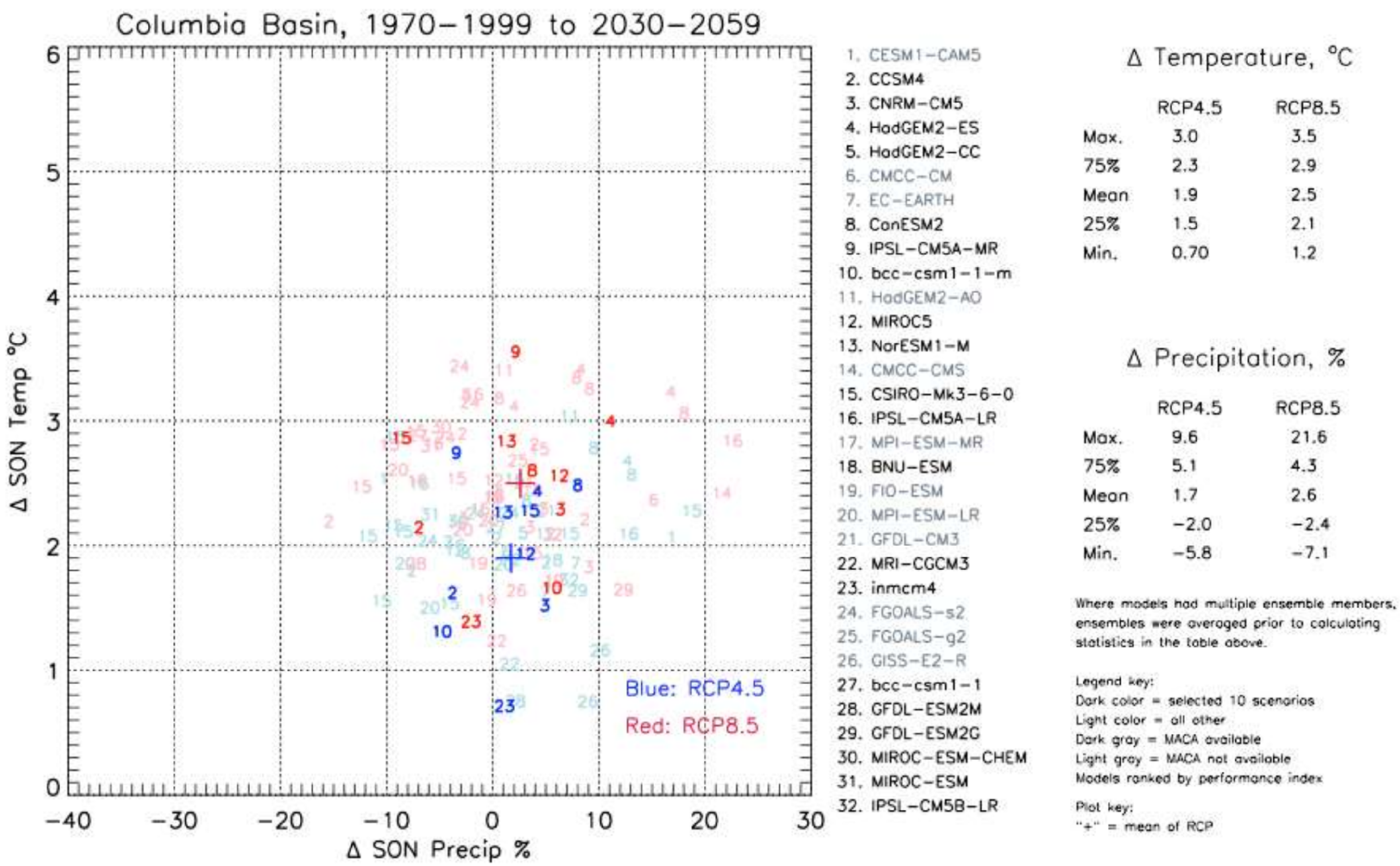


Figure 7. Projected changes in fall (SON) temperature and precipitation from CMIP5, 1970-1999 to 2030-2059. See complete figure description on page 10.

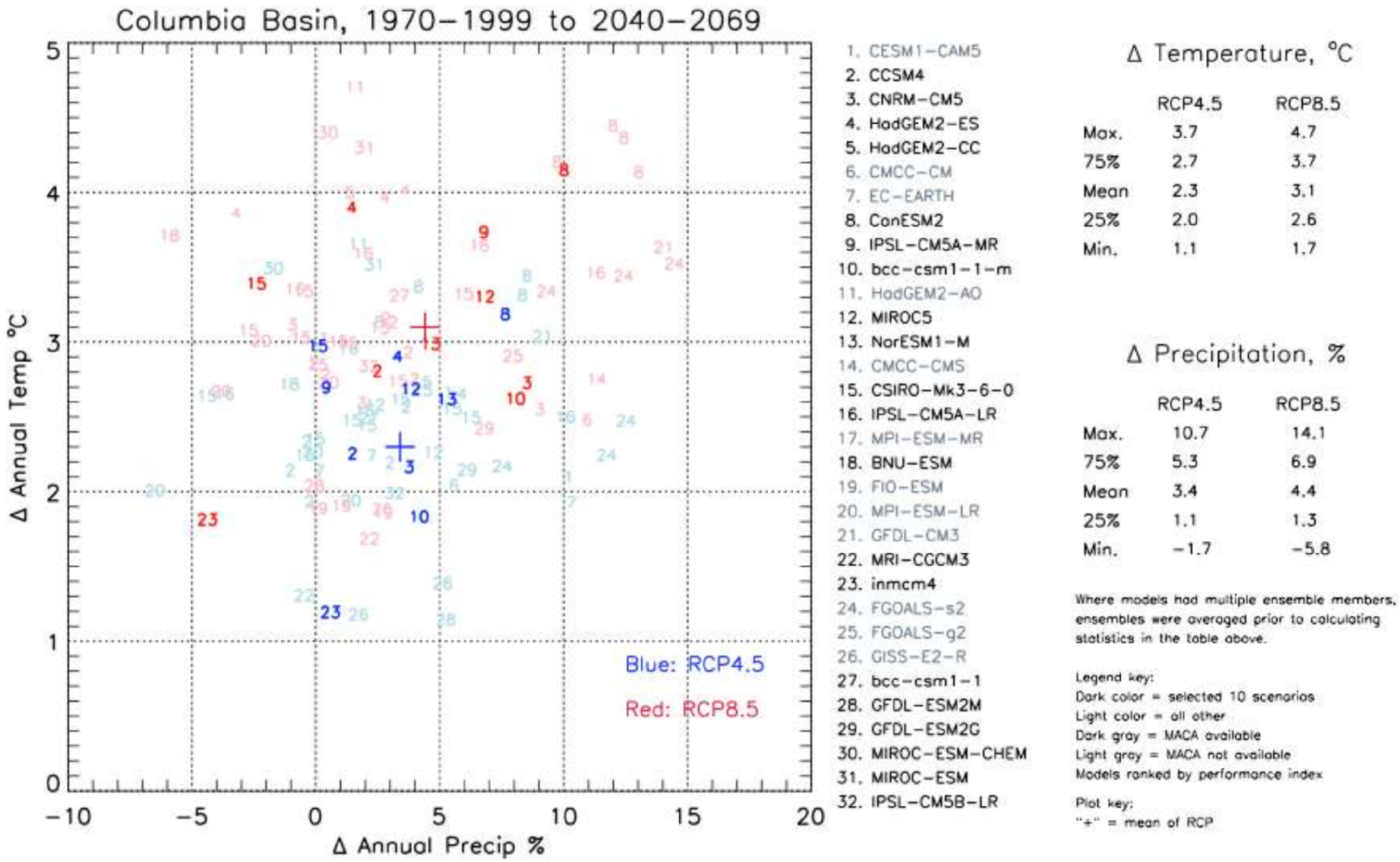


Figure 8. Projected changes in annual temperature and precipitation from CMIP5, 1970-1999 to 2040-2069. See complete figure description on page 10.

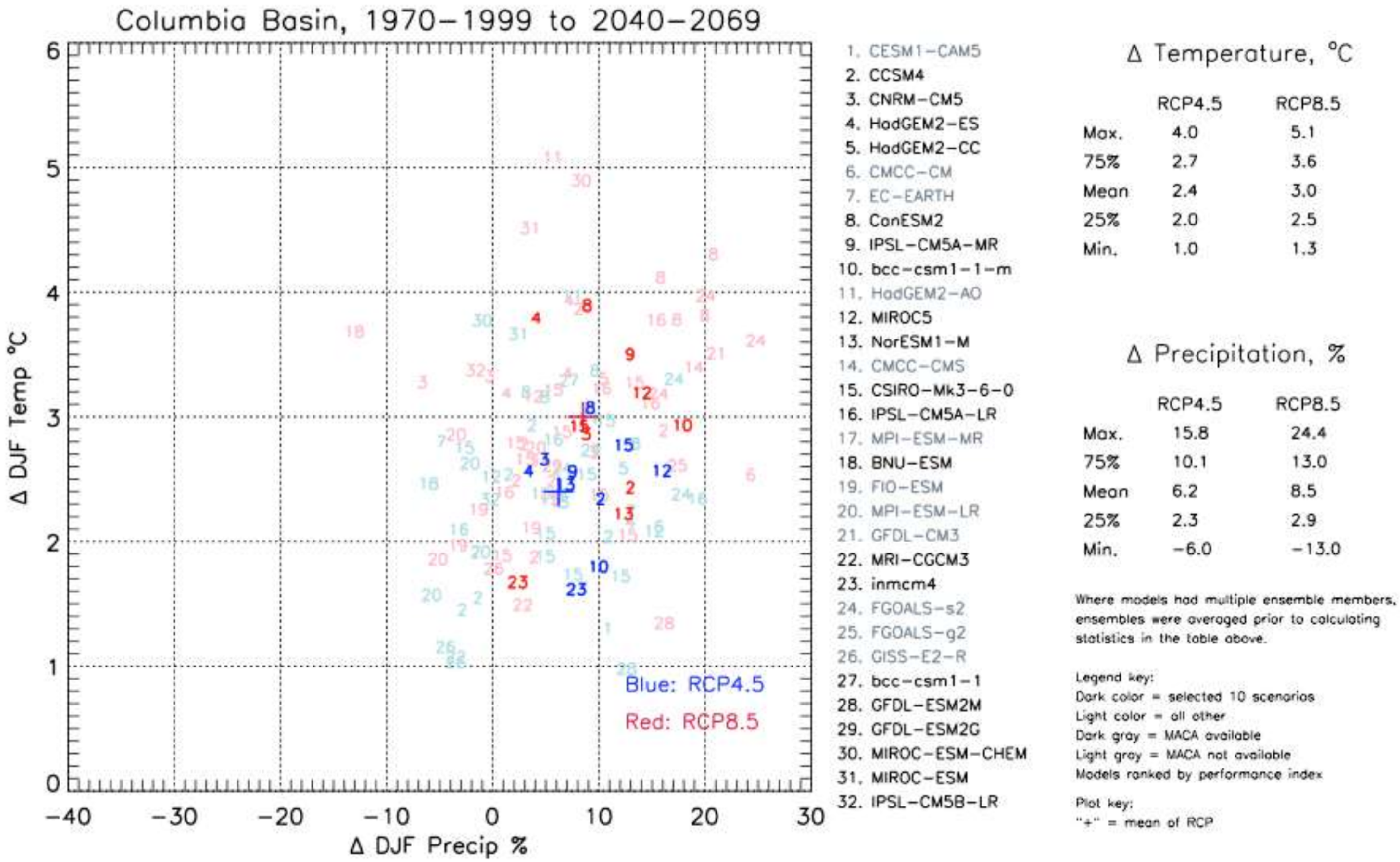


Figure 9. Projected changes in winter (DJF) temperature and precipitation from CMIP5, 1970-1999 to 2040-2069. See comletee figure description on page 10.

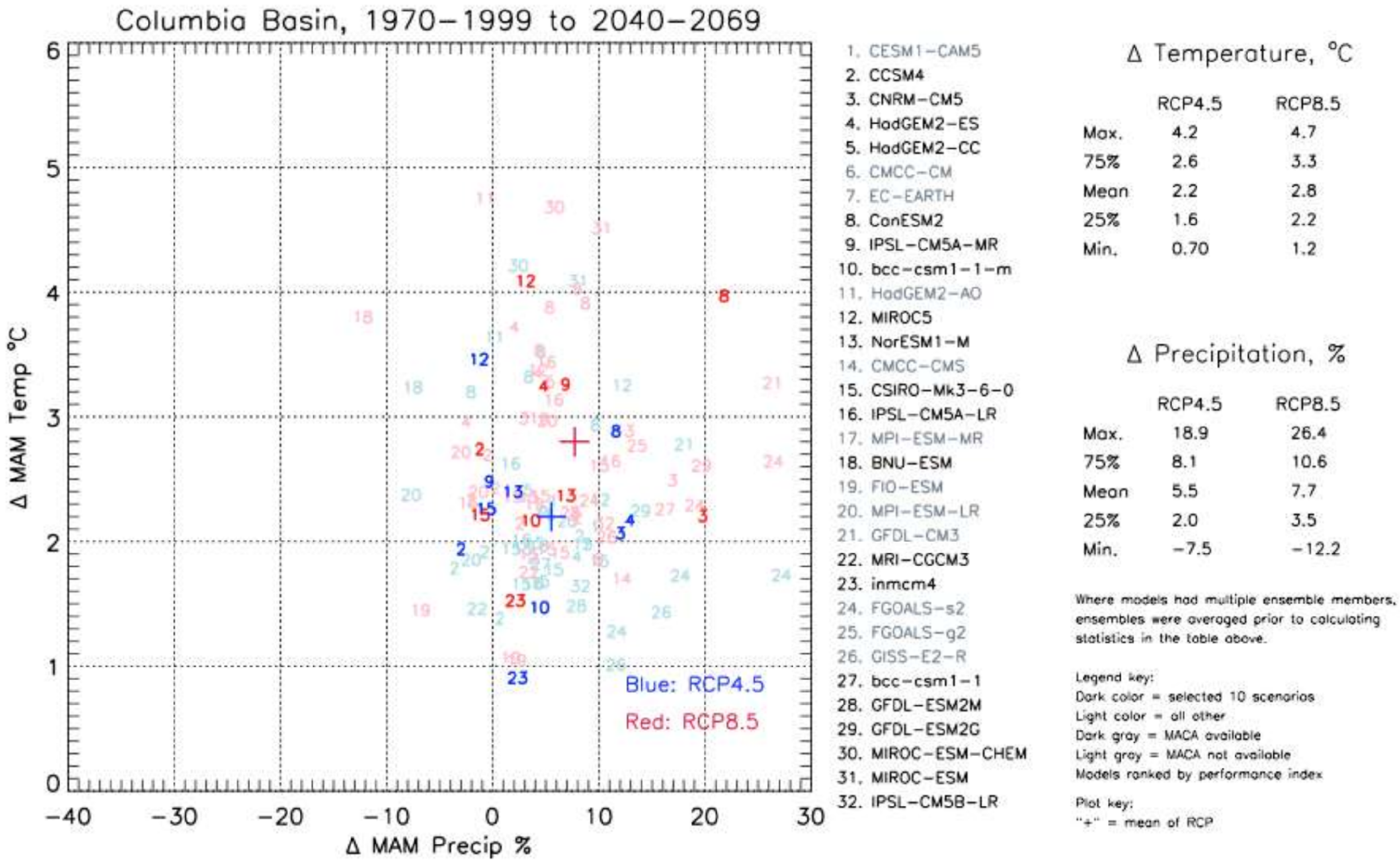


Figure 10. Projected changes in spring (MAM) temperature and precipitation from CMIP5, 1970-1999 to 2040-2069. See complete figure description on page 10.

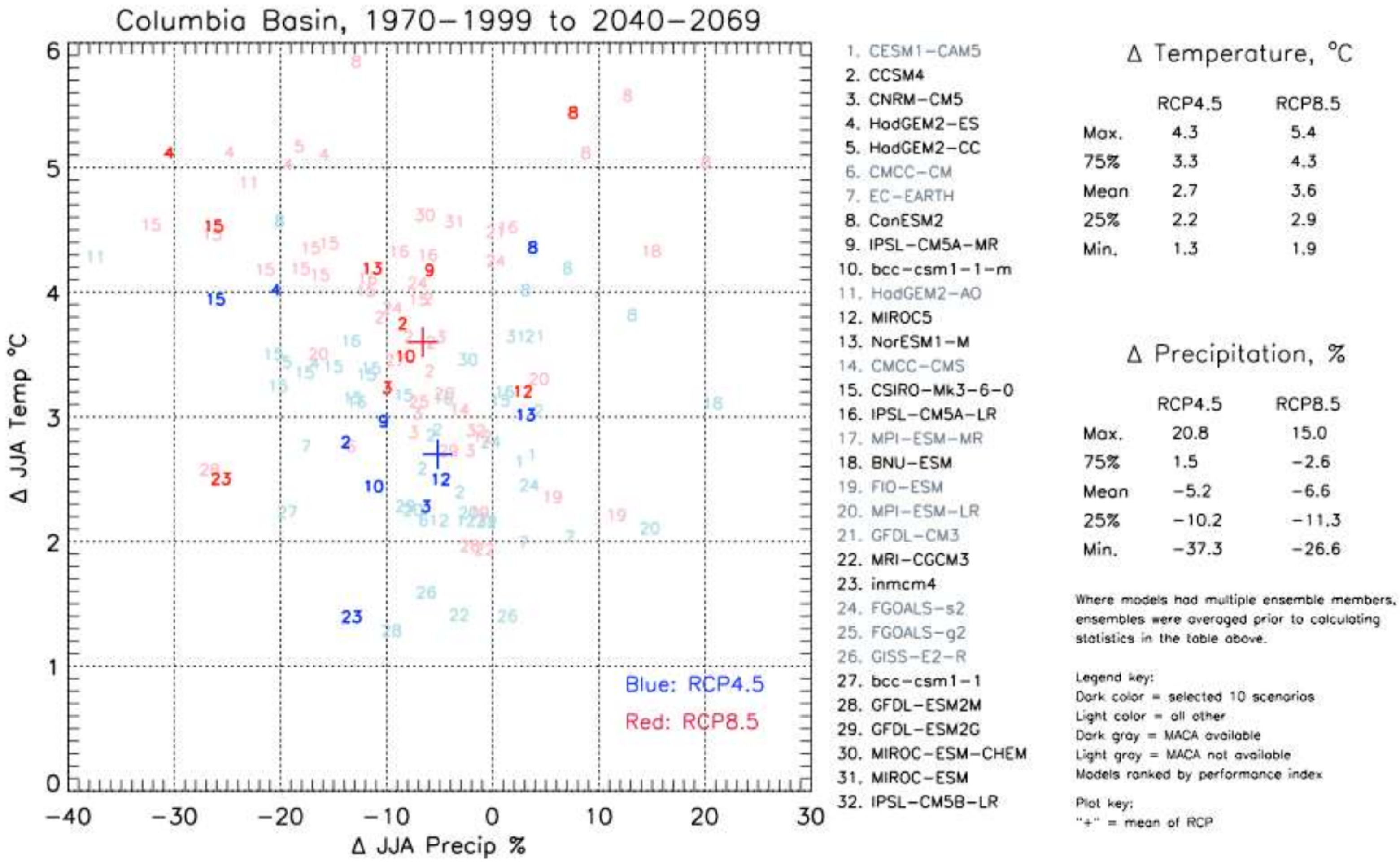


Figure 11. Projected changes in summer (JJA) temperature and precipitation from CMIP5, 1970-1999 to 2040-2069. See complete figure description on page 10.

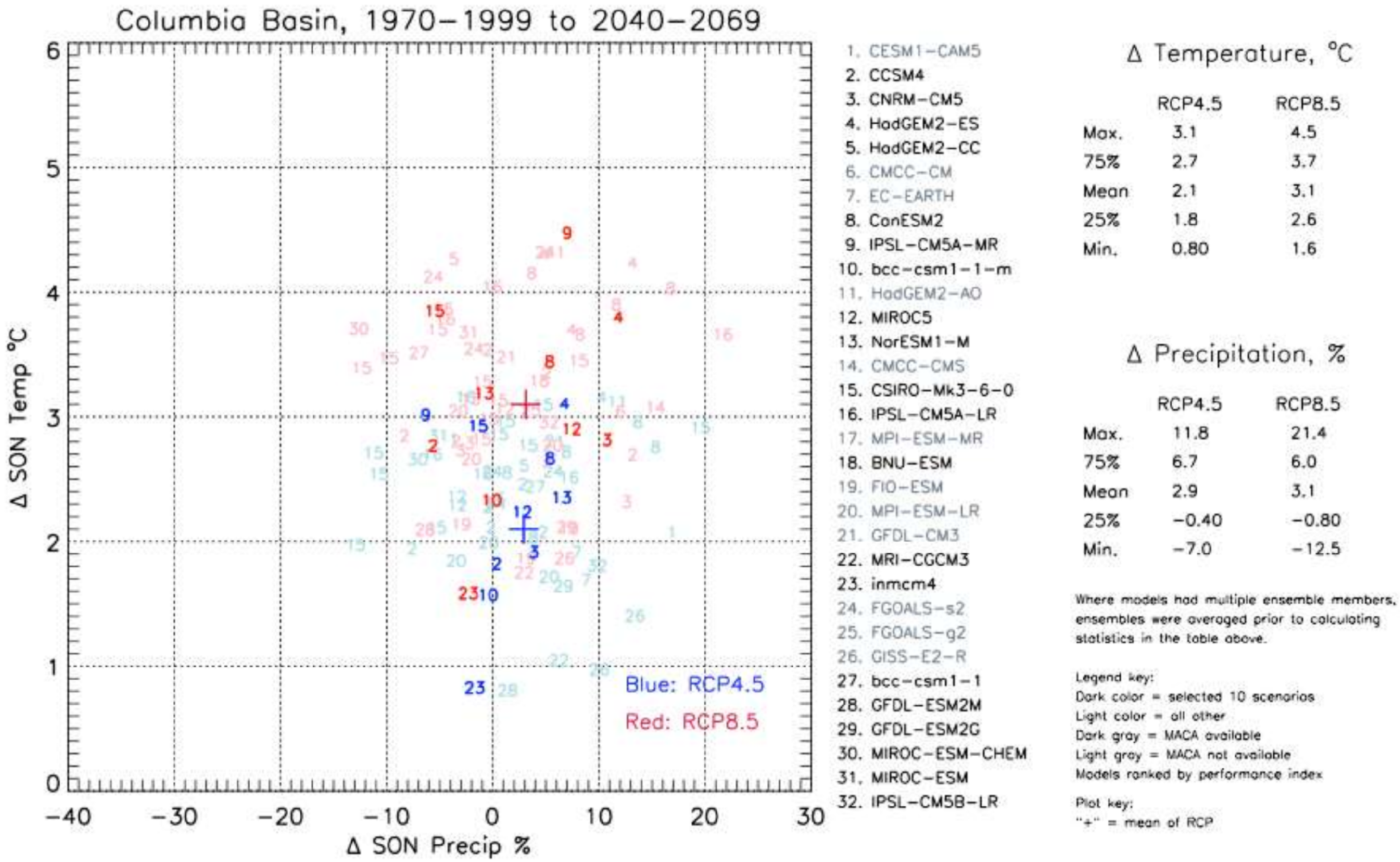


Figure 12. Projected changes in fall (SON) temperature and precipitation from CMIP5, 1970-1999 to 2040-2069. See complete figure description on page 10.

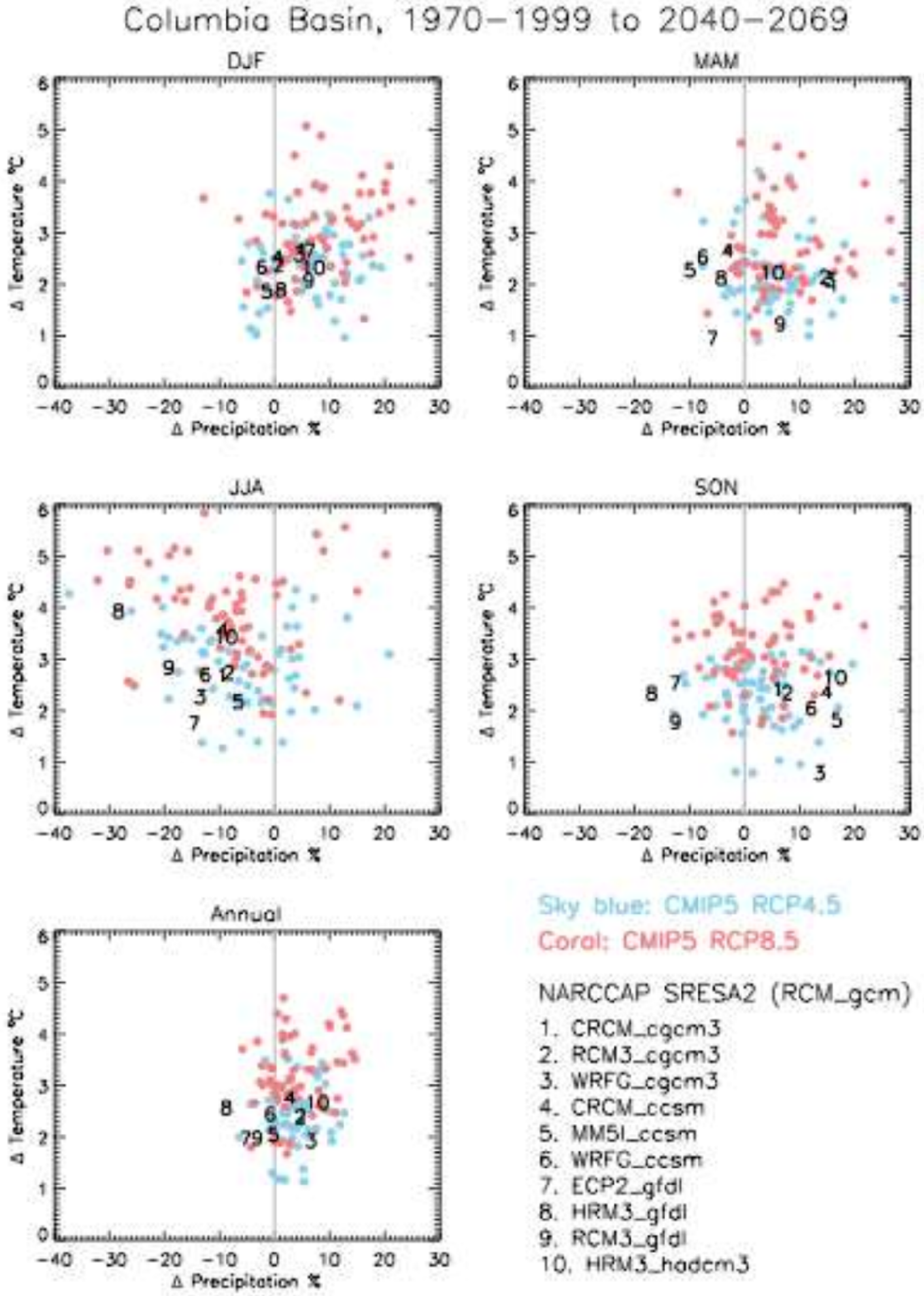


Figure 13. Changes in 30-year averaged seasonal and annual temperature and precipitation from 1970-1999 to 2040-2069 for the Columbia Basin from simulations with NARCCAP RCM-GCM combinations and CMIP5 GCMs.

Appendix A. Tables with summary descriptions of CMIP5 and NARCCAP models considered in this report.

Table A1. CMIP5 models used in this report and some of their attributes.

Model	Center	Number of ensemble members:	Atmospheric resolution (lon. x lat.)	Vertical levels in atmosphere
BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration	1	2.8x2.8	26
BCC-CSM1-1-M	Beijing Climate Center, China Meteorological Administration	1	1.12x1.12	26
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, China	1	2.8x1.4	26
CanESM2	Canadian Centre for Climate Modeling and Analysis	5	2.8x2.8	35
CCSM4	National Center of Atmospheric Research, USA	6	1.25x0.94	26
CESM1-CAM5	Community Earth System Model Contributors	2	1.25x0.94	26
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	1	0.75x0.75	31
CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	1	1.87x1.88	95
CNRM-CM5	National Centre of Meteorological Research, France	5	1.4x1.4	31
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization/Queensland Climate Change Centre of Excellence, Australia	10	1.8x1.8	18
FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	1	2.8x2.8	26
FGOALS-s2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	3	2.8x1.7	26
FIO-ESM	The First Institute of Oceanography, SOA, China	3	2.81x2.79	26
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, USA	1	2.5x2.0	48

GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory, USA	1	2.5x2.0	48
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, USA	1	2.5x2.0	48
GISS-E2-R	NASA Goddard Institute for Space Studies, USA	1	2.5x2.0	40
HadGEM2-AO	Met Office Hadley Center, UK	1	1.88x1.25	38
HadGEM2-CC	Met Office Hadley Center, UK	1	1.88x1.25	60
HadGEM2-ES	Met Office Hadley Center, UK	4	1.88x1.25	38
INMCM4	Institute for Numerical Mathematics, Russia	1	2.0x1.5	21
IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	4	3.75x1.8	39
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	1	2.5x1.25	39
IPSL-CM5B-LR	Institut Pierre Simon Laplace, France	1	3.75x1.8	39
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	2	1.4x1.4	40
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	1	2.8x2.8	80
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	1	2.8x2.8	80
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	3	1.88x1.87	47
MRI-CGCM3	Meteorological Research Institute, Japan	1	1.1x1.1	48
NorESM1-M	Norwegian Climate Center, Norway	1	2.5x1.9	26

Table A2. NARCCAP GCM and RCM definitions

Model Abbreviation	Full Name	Modeling Group
	GCMs	
GFDL	Geophysical Fluid Dynamics Lab	NOAA
CGCM3	Coupled Global Climate Model v2	Canadian Centre for Climate Modeling and Analysis
HADCM3	Hadley Climate Model v3	Hadley Centre
CCSM3	Community Climate System Model v3	NCAR
	RCMs	
CRCM	Canadian Regional Climate Model	OURANOS/UQAM
ECP2	Experimental Climate Prediction Center	UC San Diego/Scripps
HRM3	Hadley Regional Model v3	Hadley Centre
MM5I	Mesoscale Model v5	Iowa State University
RCM3	Regional Climate Model v3	UC Santa Cruz
WRFG	Weather Research and Forecasting	Pacific Northwest National Lab

Table A3. NARCCAP RCM/GCM combinations evaluated

		AOGCM			
		GFDL	CGCM3	HADCM3	CCSM
RCM	CRCM		X		X
	ECP2	X			
	HRM3	X		X	
	MM5I				X
	RCM3	X	X		
	WRFG		X		X

BPA Technology and Innovation Monthly Report
TIP 304: Predicting the Hydrologic Response of the Columbia River System to Climate Change
Date: 6/26/2014
PM: Erik Pytlak
PIs: Dennis Lettenmaier, Bart Nijssen
Project Status: **Green**

Meeting Attendees: Erik Pytlak, Oriana Chegwidden, Bart Nijssen, Toni Turner, Jason Ward, Keith Duffy

Progress This Month:

- **Task 4, Parameter Estimation: Underway.** UW continues to experiment with the alternate, inverse hydro model calibration method. They have run tests of this method in the Naches and Pend Oreille basins, and are about to check the results against the historic (NRNI) flows, and to make sure the results make sense. They should have results in 2-3 weeks, which will be the decision point as to either use this new method which has the potential to allow for calibration at a much finer resolution, or to calibrate the three hydrologic models using traditional methods, which will not allow as much spatial detail (instead all grid cells in a subbasin would be treated in a similar manner). Erik invited the team to share any comparison results with the RMJOC parties, especially the Corps which is most interested in capturing the flow peaks accurately.
- **Followup to Task 1:** The team has had to do some unexpected debugging and recoding of the statistical glacial model they selected last month. They are discussing whether calibration of one parameter is necessary for model validation. Bart is consulting experts with the Pacific Climate Impacts consortium (PCIC) who used a similar glacier modeling approach in their 2010-11 work with BCHydro , and participated in the transboundary workshop in January 2014. Erik reminded Bart and Oriana that they do have some travel budget for a visit to Victoria, BC, if they need it.
- **NRNI upper Snake flow updates:** Reclamation shared their draft set of flows with BPA and the Corps in early June. Both entities discovered sizable differences between the Corps and Reclamation calculated unregulated flows at Brownlee in critical high water/flood years. Time is now becoming a little more critical for Reclamation to complete the NRNI flows for the upper Snake, and to resolve differences between Reclamation and Corps flows at Brownlee, or it may cause a delay with completing the calibrations UW will begin in August. All 3 agencies are continuing to look at the two datasets to see if the differences can be resolved, or at least explained.
- The next CRFG meeting has been moved to September 25th. Although most of the time will be allotted to the PSU climate change project, there will be time for UW to present any additional progress – particularly on the inverse routing method should they adopt it for model calibration in Stage Gate 3, which I scheduled to begin in October.
- PI Dennis Lettenmaier has accepted a faculty position at UCLA, and thus will be leaving as PI of this project. However, Bart Nijssen will quickly transition into that role. He and the UW contracting staff are currently working to restructure some of the cost-share funding. Once that is complete, CO Matt Delong will work with UW Contracting to revise the contract as needed.

BPA Technology and Innovation Monthly Report
TIP 304: Predicting the Hydrologic Response of the Columbia River System to Climate Change
Date: 3/11/2015
PM: Erik Pytlak
PIs: Bart Nijssen
Project Status: Green, but see comments below.

Meeting Attendees: Bart Nijssen, Erik Pytlak, Kristian Mickelson, Bob Lounsbury, Keith Duffy, Jeremy Giovando

Progress This Month:
Task 4, Parameter Estimation: All three model configurations are now complete. The way the models are set up, it is now easy for the team to quickly rerun calibrations as needed, which will give the project more analysis time as the project enters Stage Gate 4/Tasks 6 and 7. Work completed as part of Task 5 indicates that they will need to complete calibration reruns for all three models.

Task 5, Hydrologic Model Sensitivity: Underway, but likely will not be complete until late April. Sensitivity studies have helped to identify two key areas where the calibrations have not matched well with historical streamflow behavior:

1) Initial VIC model calibrations are holding onto snow too long in the spring. The team discovered that different historical data can yield pretty different calibration results, with the oldest of the historical temperature and precip datasets performing the best (the same historical dataset used in RMJOC-I). While this result is unsatisfying, it is a key discovery in the project thus far: that there are pretty significant differences in which historical data you use – particularly when calibrating on daily time steps. The team is hoping to resolve this issue when the Pacific Climate Impacts Consortium (PCIC) publishes an updated gridded temperature and precipitation dataset for British Columbia. Incidentally, that work is also being co-funded by BPA.

2) Calculation issues in the NRNI dataset were uncovered. Reclamation depletions from Brownlee, the Yakima, and the Deschutes basins, which were correct and accurate, are not properly routed downstream, which caused a low streamflow bias for all lower Columbia and Lower Snake segments. In addition, irrigation depletions above Grand Coulee were added instead of subtracted – which led to a high bias, and tended to mute the errors downstream where quality control was generally focused when the previous NRNI versions were published. The Corp has since recalculated all flows throughout the basin, and the biases appear to have been corrected. Also the annual volumes also appear to match expectations articulated in the 2010 Modified Flows documentation: there is about 16 to 18 maf of irrigation depletion in the Columbia River Basin above The Dalles, with about 10 maf of that in the middle and upper Snake basin. In most cases, the corrected NRI flows will improve the calibration statistics, and identify calibrations that may actually be good, or even better than expected, in initial runs.

- **Task 6, Climate Model Selection (Part of Stage Gate 4 to be activated in April).** Based on peer review and feedback from the RMJOC-II Workshop on February 19-20, the Oregon State researchers are going to take one more look the initial GCM selection to see if some of the ones "on the bubble" can be ruled in or out based on how they resolve large scale, synoptic weather patterns. **This can occur completely independently of Task 5. Thus, the project remains "green" as overall budget, scope and schedule remain unaffected.**

Upcoming events:

- Once the updated NRNI flows have received a thorough quality control check by both BPA and the Corp, Erik will invite the Columbia River Intertribal Fish Commission (CRITFC) technical staff to look at the NRNI dataset, compare the to the 2010 Modified Flows and offer any suggestions, comments or concerns we'll need to address in documentation
- The Corp is about 80% complete with NRNI documentation. Reclamation has not started with their documentation efforts. Erik suggested Reclamation take a look at the RMJOC-I documentation to give them a sense on the level of detail that will probably be needed -- rather technical, but not too deep, and not to the exact, individual diversion or project level. Erik is suggesting a first draft be completed by June or July, subject to staff availability during peak runoff season.
- The RMJOC-II notes and slides will be shared with attendees in April.

BPA Technology and Innovation Monthly Report
TIP 304: Predicting the Hydrologic Response of the Columbia River System to Climate Change
Date: 6/3/2015
PM: Erik Pytlak
PI: Bart Nijssen
Project Status: Green.

Meeting Attendees: Bart Nijssen, Oriana Chegwidden, Erik Pytlak, Kristian Mickelson, Bob Lounsbury, Keith Duffy, Jason Ward

Progress This Month:
Task 4, Parameter Estimation: Complete.
Task 5 Hydrologic Model Sensitivity: In progress, nearing completion.
Calibration of all three hydrologic models is complete, and results from validation runs were shared via a short Powerpoint prepared by UW. Both PRMS and VIC show similar monthly streamflow performance. With the exception of isolated, small watersheds like the Clackamas and Santiam Rivers, or heavily groundwater-influenced points on the Deschutes and far upper Snake Basins, both PRMS and VIC calibrations closely match the corrected NRNI historic flows.

However, a large bias is noted in the ULM's NOAH Land Surface Model, particularly in mixed rain/snow dominated basins, even after calibration. It appears its snow is melting earlier, which in turn is leading to earlier runoff. In addition, the ULM volumes are about 10% higher than the other two models, possibly because the spring runoff happens earlier making it less available for evaporation. Earlier snow melt is a known problem with the NOAH LSM. Because the biases are known and predictable, bias correction should correct this bias. However, it will be critical to convey this issue to decision-makers once climate change streamflows are generated, because the bias correction could noticeably affect the model for streamflow later in the century.

Task 6, Climate Model Selection: Underway
Oregon State University continues its assessment of the best GCMs. Based on the suggestions from the February workshop and subsequent work, two of the 10 selected GCMs may be changed to ones that better represent actual atmospheric processes which broader-brush temperature and precipitation statistic measures did not fully capture.

Task 7, Downscaling and Bias Correcting Atmospheric (temp and precip) Forcings: Getting started. The UW team will be meeting to inventory currently available (i.e. off-the-shelf) software to complete the BCSD downscaling. UW has also been in contact for some time with University of Idaho for the MACA dataset. This is the stage where TIP309 (the terminated PSU climate change research project) encountered major data quality problems, which they did not catch for several months and ultimately crippled the project itself. UW is reviewing which version of the historical Livneh data set to use as the basis for the downscaling process, since that dataset has been updated in the Canadian part of the basin since the release of the MACA downscaled climate forcings..

UW has also been in contact with Oak Ridge National lab to obtain a subset of their dynamically downscaled climate change dataset. This is a stretch target of the UW project, but with this data now available, there is a good chance this project will be able to generate streamflow projections. The downside, though, is that it will reduce the possibility that an initial round of streamflows will be ready for RMJOC use earlier than planned in the research agreement. See note below.

Other developments:

- At the May RMJOC meeting, the committee gave the climate change technical team instructions to begin developing the procedure for incorporating forecast uncertainty in the hydroregulation studies. For the RMJOC-I study, statistical weather supply equations in use at the time were modified to incorporate climate change temperature, precipitation, and snow-water equivalent. However, there were challenges with this approach, including the fact that the forcing data is in 2-dimensional grids, while the water supply equations use single point (1-dimensional) data.

  Since 2009, all water supply equations have since been updated, but none of them were calibrated using a historical record going back more than about 20 years. In addition, the largest project of the basin (Grand Coulee) and Brownlee are now operated using ESP forecasts. Because of the within-month benefit ESP forecasts provide, it is unlikely that much of the basin will still be using statistical water supply equations for within-season operations by 2020-2030. There is also a decent chance that the forecast periods currently in use (April-August or May-September) could change to adapt to climate change. Thus the questions become how to generate forecasts and their uncertainty bands, which forecast periods to use, and whether it's important to anticipate future forecast methods when climate change uncertainties this far in advance may overwhelm any incremental benefits in forecast methodology. This will be an ongoing conversation, but initial suggestions are to be presented by the July meeting. BPA and the Corp have begun internal brainstorming discussions, and will share those initial ideas between each other in our June 22nd check-in.

- Also at the RMJOC, the request was made to contact UW to evaluate the possibility of accelerating climate change streamflow delivery – particularly for use in the 2018 Biological Opinion. There is considerable scientific risk in accelerating this kind of research, but additional financial resources may be available. UW has agreed to go back and review whether they may be able to either streamline some processes or perhaps stagger the delivery of the climate change streamflows from the various models and downscaling datasets. The UW will provide initial feedback on this as part of the next monthly meeting (end of June).

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BPA Technology and Innovation Monthly Report
TIP 304: Predicting the Hydrologic Response of the Columbia River System to Climate Change
Date: 9/12/2014
PM: Erik Pytlak
PIs: Bart Nijssen
Project Status: Green, but Stage Gate 2 completion will be delayed by about one month.

Meeting Attendees: Oriana Chegwidden, Erik Pytlak, Joe Hamann, Matt Stumbaugh, Kristian Mickelson, and Jeff Arnold (USACE Climate Change Science Lead). Meeting was in person at University of Washington on September 8.

Progress This Month:

- **Task 4, Parameter Estimation: Underway, but task completion will likely be delayed until around November 1.** UW continues to work on the distributed runoff field hydro model calibration method. More details were in the previous month's report. The delay is well-managed and will not hinder the team's ability to execute initial Stage Gate 3 tasks.
- The project team gave Erik and the RMJOC technical teams a one hour tutorial on the distributed runoff field/auto-calibration technique on September 3rd. This gave us a very good sense of how the technique works, and will serve as a starting point for project documentation, which we're hoping to begin over the winter in 2015.
- At our September 8th meeting, Joe gave the team a more detailed overview of the glacier modeling component he has built for VIC. Initial runs indicate it can accurately develop and ablate glaciers (i.e. spread a glacier downhill before melting it), and is able to represent glaciers already in place across the basin – especially in British Columbia. Initial hydrologic test runs using this model are ready to go for the full scale hydrologic modeling. At the same meeting, Oriana gave a short presentation to Kristian, Erik and Jeff Arnold, who is now a matching funder for the project, on project progress to date and next steps.

Administrative changes for Project Year 2

- Ishottama, who was a member of the project team, has left the project and will be replaced by Matt Stumbaugh (after his current project is completed).
- Budget accruals have been submitted to cover work done in September, but will be invoiced after the fiscal year ends. Based on expected September expenses and the planned October accrual, the project is on target to use all of its FY14 allocated funds.

Upcoming events:

- State Gate 3 is likely to be approved later this month since some of that work can begin concurrently with any remaining potions of Task 2 are completed.
- The next CRFG meeting has been moved to September 25th. UW is invited to give an overview of their project status, if they wish.

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RMJOC

RMJOC Climate Change Initiative

Sovereign Technical Team
Climate Workshop

Presented by:

August 8, 2011

RMJOC

RMJOC

- The Joint Operating Committee (JOC) was established through the Direct Funding Memorandum of Agreements (MOAs) between BPA, Reclamation, and the Corps for the asset planning, maintenance, and operation of the FCRPS.
- The River Management Joint Operating Committee (RMJOC) is a sub-committee specifically dedicated to reviewing the practices, procedures, and processes of each Agency to identify changes that could improve the overall efficiency of the operation and management of the FCRPS projects.

RMJOC

RMJOC Motive and Need

- Motive
  - consistent incorporation of climate projection information into Agencies' longer-term planning studies

- Need
  - adopt common dataset (climate and hydrology)
  - establish consensus methods for data use
  - efficiently use limited resources through coordinated development of data and methods

FCRPS
FEDERAL COLUMBIA RIVER POWER SYSTEM
RMJOC

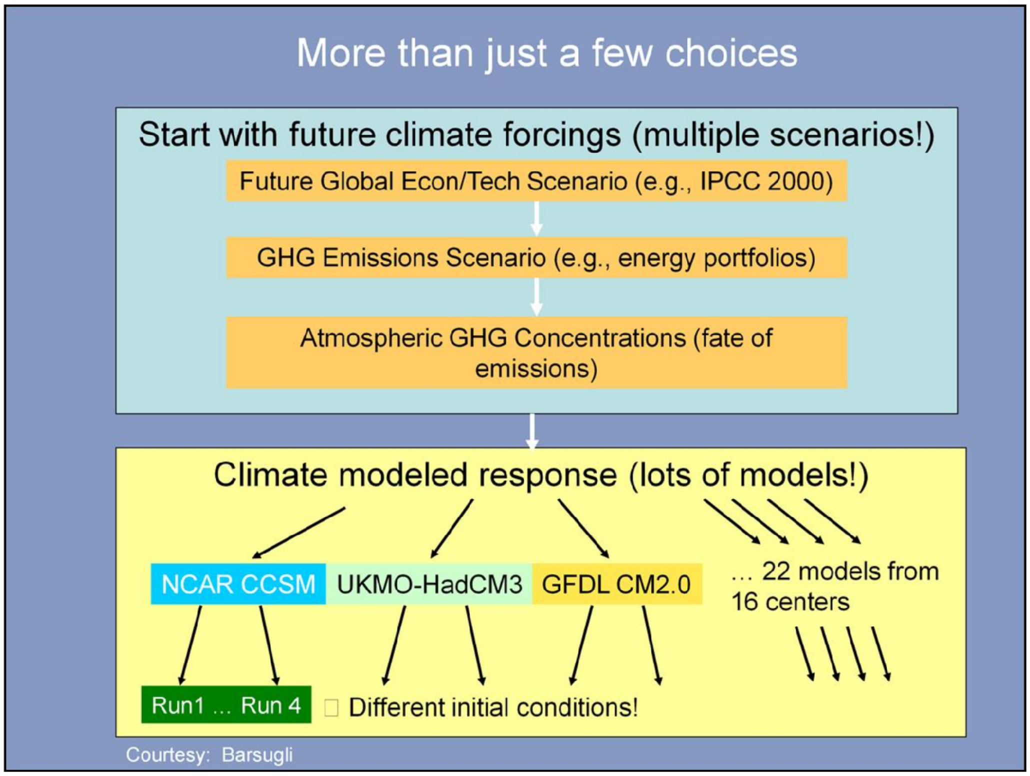
Key Scoping Decisions

1. Start with existing CIG's data on regional climate and hydrology (CIG's "HB2860" regional project)

2. Use two methodologies from CIG
   - Step-change climate information (Hybrid-Delta)
   - Time-developing climate information (Transient)

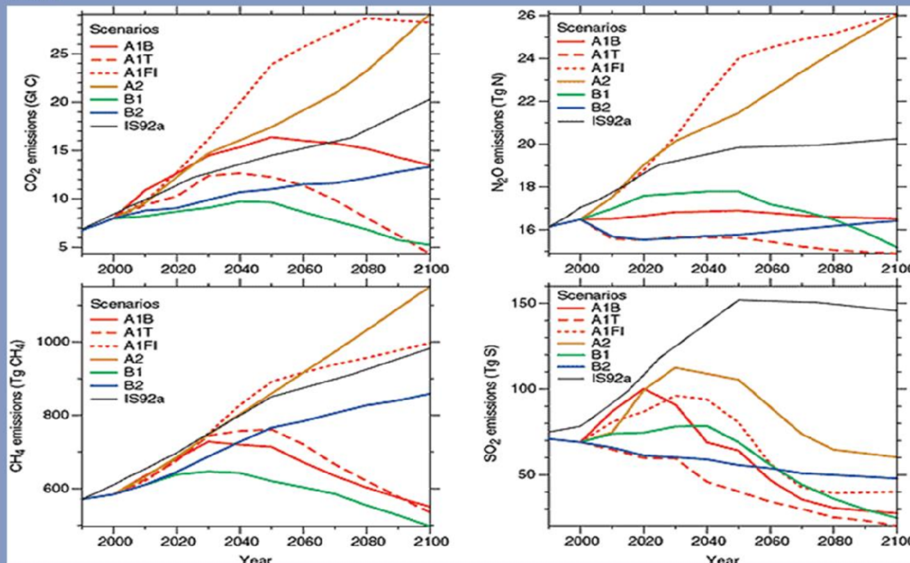
3. Use only a subset of both data sets

4. Conduct modeling and analysis using both types (Hybrid-Delta and Transient)
   - Look at overall climate change impacts
   - Draw impressions on which types might be more appropriate for Agencies' longer-term planning


More than just a few choices
Start with future climate forcings (multiple scenarios!)
Future Global Econ/Tech Scenario (e.g., IPCC 2000)
GHG Emissions Scenario (e.g., energy portfolios)
Atmospheric GHG Concentrations (fate of emissions)
Climate modeled response (lots of models!)
NCAR CCSM
UKMO-HadCM3
GFDL CM2.0
… 22 models from 16 centers
Run1 … Run 4
Different initial conditions!
Courtesy: Barsugli

Emission Scenarios

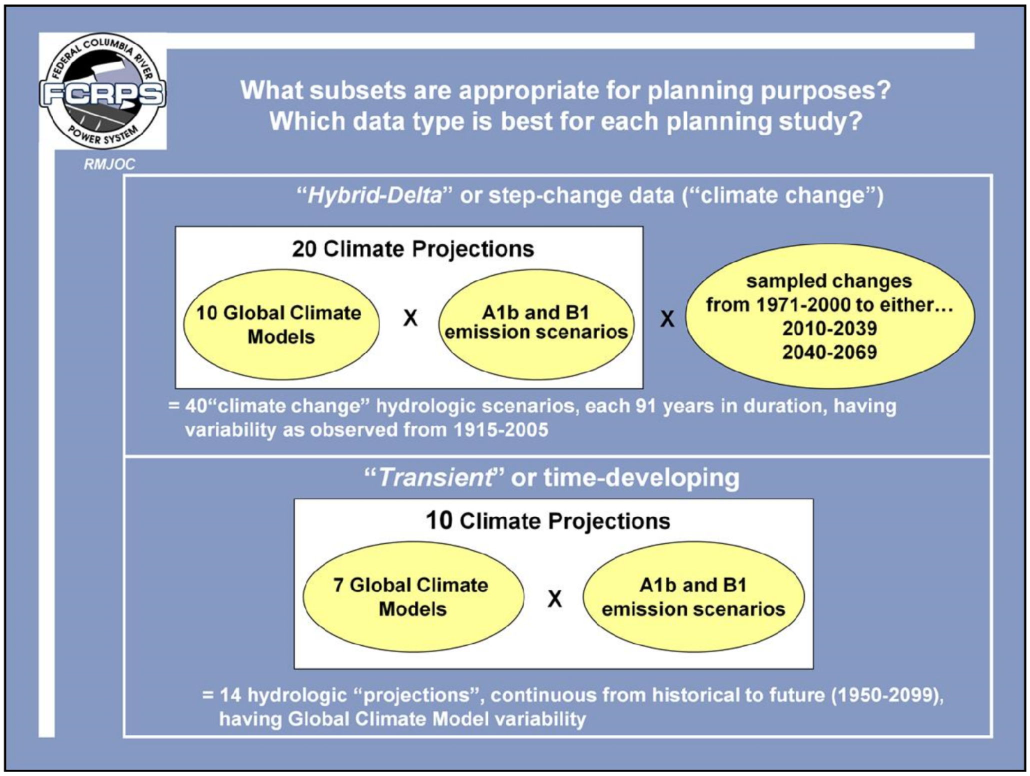
RMJOC



RMJOC

Original Data from CIG Effort

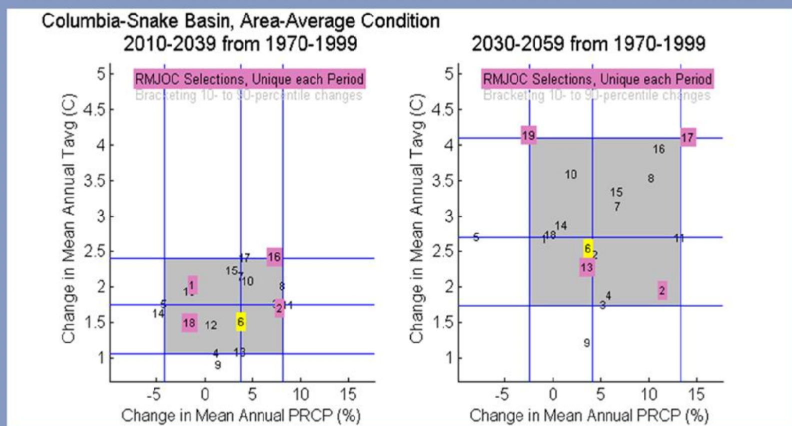
- Developed historic meteorological data at 1/16th degree (7 kilometer) from 1915- 2005
- Developed downscaled 1/16th degree meteorological data sets associated with each of 10 GCM scenarios for “2020s” “2040s” “2080s” time periods
- Ran the 1/16th degree VIC hydrologic model for each of 10 GCM scenarios for the three time periods, and produce streamflow scenarios for over 200 inflow locations
- Bias adjust VIC flows to estimated monthly Modified Flows for all Hydsim and Genesys sites


FEDERAL COLUMBIA RIVER
FCRPS
POWER SYSTEM
RMJOC
What subsets are appropriate for planning purposes?
Which data type is best for each planning study?
"Hybrid-Delta" or step-change data ("climate change")
20 Climate Projections
10 Global Climate Models
X
A1b and B1 emission scenarios
X
sampled changes from 1971-2000 to either…
2010-2039
2040-2069
= 40"climate change" hydrologic scenarios, each 91 years in duration, having variability as observed from 1915-2005
"Transient" or time-developing
10 Climate Projections
7 Global Climate Models
X
A1b and B1 emission scenarios
= 14 hydrologic "projections", continuous from historical to future (1950-2099), having Global Climate Model variability

RMJOC

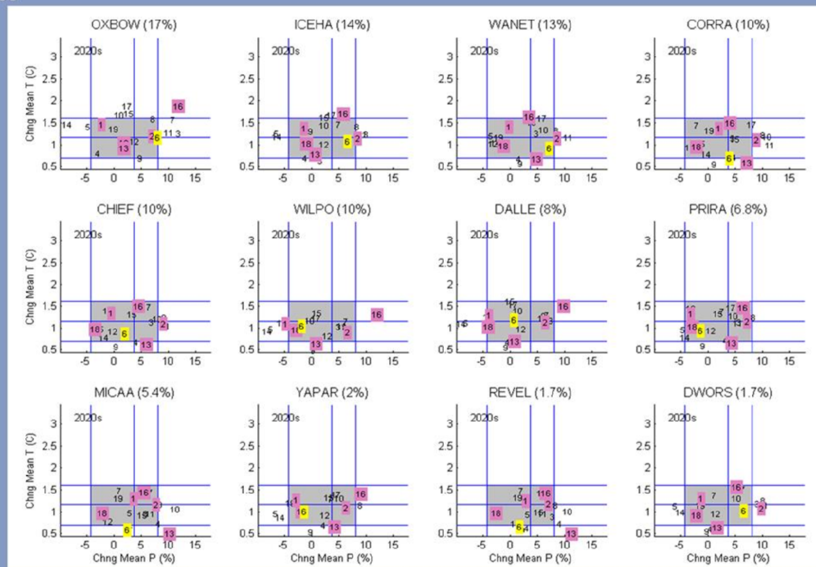
How to select the scenarios…

- 10 and 90 percentile brackets?
- 25 and 75 percentile brackets?
- Unique to each period?
- Based on which inflow points?



RMJOC

Selected Scenarios: Sub-basins



Summary of Projections Selected

				Hybrid Selections						
				2020s			2040s			
Number		GCM [2]	Emissions Scenario	Selected (Labels) [3]	Change in P (in) [4]	Change in T (ºC)	Selected (Labels)	Change in P (in)	Change in T (ºC)	Transient (x = selected, o = not selected)
1	√	ccsm3	B1	MW/D	-1.2	1.4		-0.8	1.8	x
2	√	cgcm3.1 t47	B1	LW/W	7.9	1.1	LW/W	11.5	1.3	x
3		cnrm cm3	B1		7.5	1.2		5.3	1.2	o
4		echam5	B1		1.3	0.7		5.9	1.2	o
5	√	echo g	B1		-4.2	1.2	LW/D	-7.9	1.8	x
6	√	hadcm	B1	C	3.8	1.0	C	3.7	1.7	x
7		ipsl cm4	B1		3.8	1.4		6.9	2.1	
8		miroc 3.2	B1		8.1	1.3		10.4	2.3	
9		pcm1	B1		1.5	0.6		3.6	0.8	o
10		ccsm3	A1b		4.6	1.4		2.0	2.4	o
11		cgcm3.1 t47	A1b		8.8	1.2		13.4	1.8	o
12		cnrm cm3	A1b		0.8	1.0		4.1	1.6	o
13	√	echam5	A1b	MC	3.7	0.7	MC	3.7	1.5	x
14		echo g	A1b		-4.7	1.1		0.9	1.9	o
15		hadcm	A1b		3.0	1.5		6.7	2.2	o
16	√	ipsl cm4	A1b	MW/W	7.4	1.6		11.2	2.6	
17	√	miroc 3.2	A1b		4.2	1.6	MW/W	14.2	2.7	
18	√	pcm1	A1b	LW/D	-1.5	1.0		-0.2	1.8	x
19 [1]	√	hadgem1	A1b		-1.5	1.3	MW/D	-2.5	2.8	

Notes

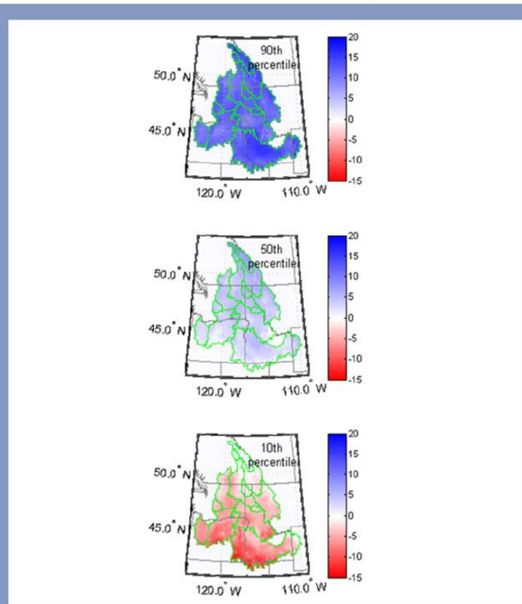
[1] Number 19 was not included in Oct 24 workbook shared with stakeholders.

[2] Green shaded GCMs are those that BC Hydro suggested as being part of a "better set of GCMs." (Dec 2, Frank Weber email)

[3] Selected Labels: MW = More Warming, LW = Less Warming, W = Wetter, D = Drier, MC = Minor Change, C = Central Change

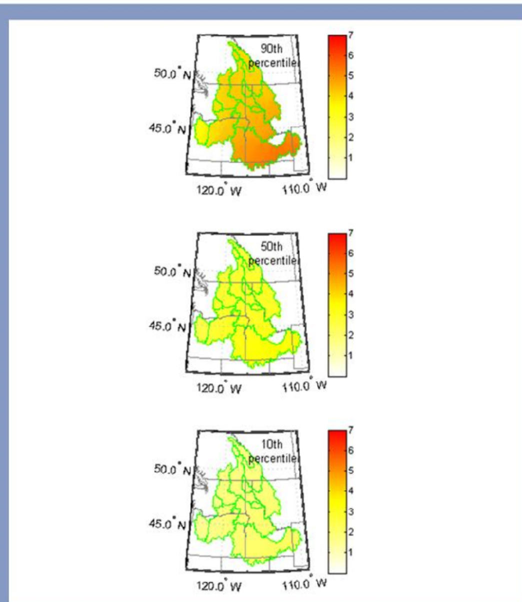
[4] P = precipitation, T = average daily temperature, "Change in" means change in 92-year period-mean annual condition. For assessing change, the reference is Observed Climate Variability, 1916-2006. The changed condition is the 92-year Observed Climate Variability sequence adjusted to match climate characteristics of a projected 30-year period (2020s = 2010-2039 and 2040s = 2030-2059) from the given underlying climate projection (column Number).

RMJOC



Projected change in mean annual precipitation (%) over the Columbia-Snake River Basin, from 1970-1999 to 2030-2059

12



Projected change in mean annual temperature (ºF) over the Columbia-Snake River Basin, from 1970-1999 to 2030-2059

13

RMJOC

Additional Development

- Water Supply Forecasts
  - Created “synthetic” volume forecasts to reflect climate altered conditions at the time of forecast (snowpack, precipitation, runoff)
  - Also developed perfect knowledge volumes from streamflows
- Rules Curves
  - Using synthetic volume forecasts, compute synthetic rule curves (flood control, variable energy refill curves)

RMJOC

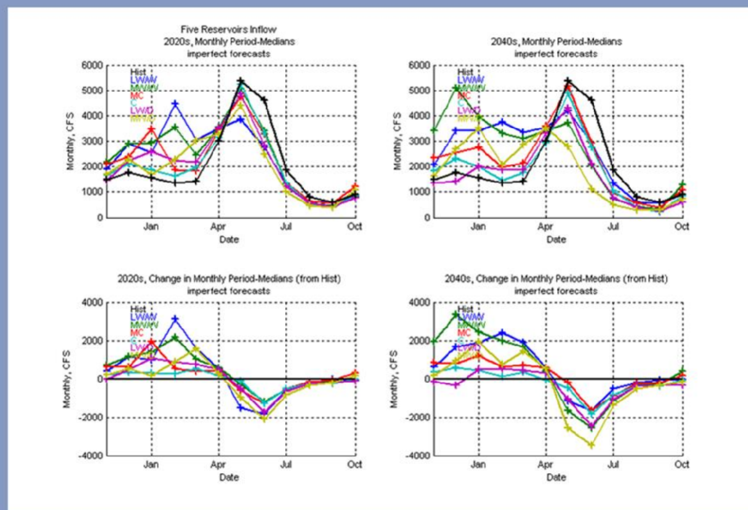
Reclamation Tributary Basins General Results

- Increased winter runoff, less spring/summer runoff
- Increased storage needs in the spring, greater drawdown in summer months than historically
- Reclamation flood control curves self-adjusting
- Increased reliance on stored water vs. natural flow

15

RMJOC

Yakima River – Flow Example



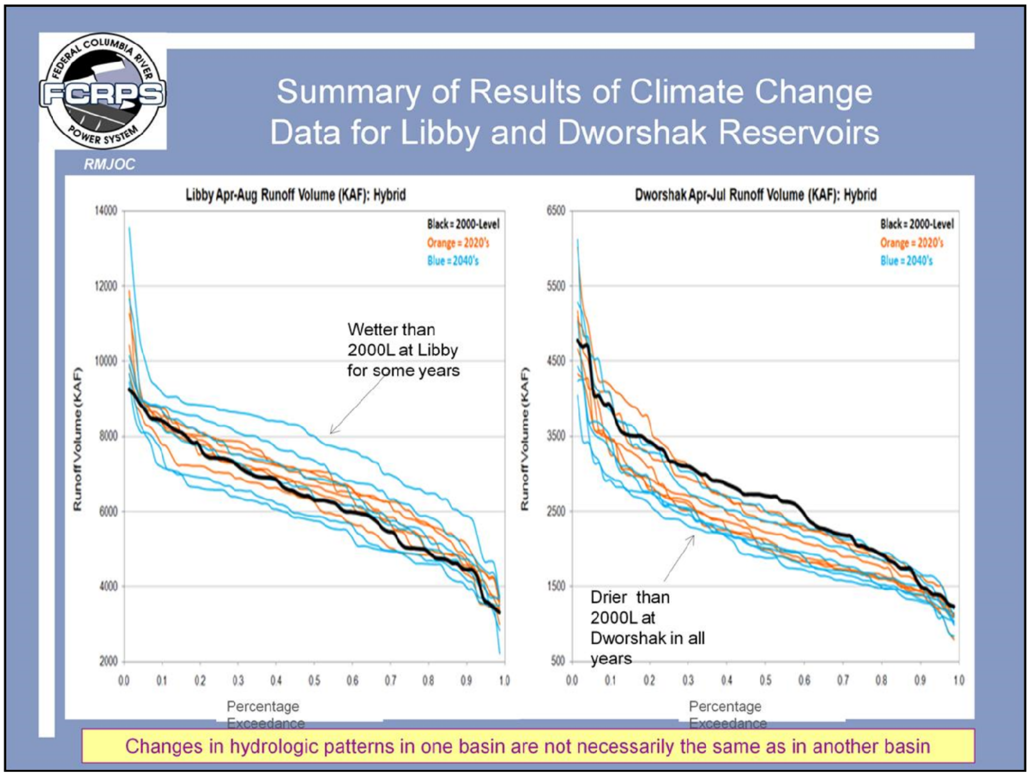
Familiar story: Warming leads to more winter runoff;
Less spring-summer runoff;
Lower flows in river in late summer.

16

RMJOC

Flood Control – Approach and Limitations

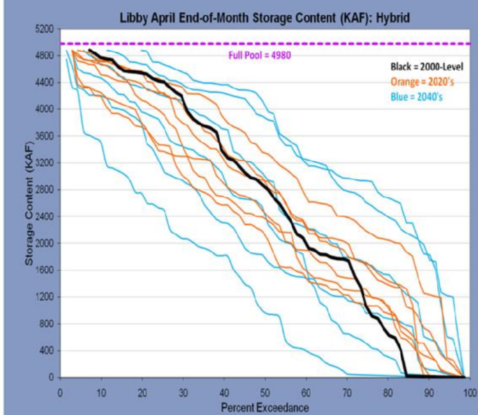
- Monthly time step and 70-year streamflow period rather than daily modeling due to time, data, and model limitations
- Assumed use of current flood control storage reservation diagrams & procedures rather than developing new diagrams/procedures in response to climate change
- Analysis focused on end-of-month flood control requirements during evacuation period and only estimated flood control requirements during the refill period

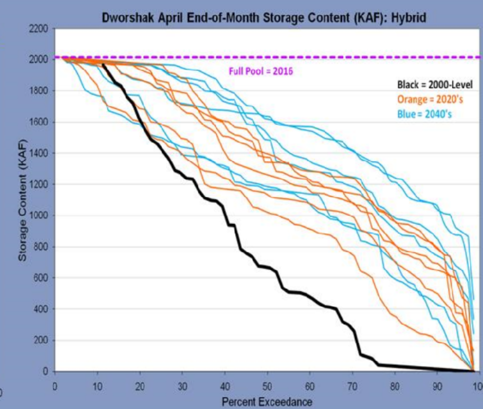


Change in hydrologic patterns in one basin are not necessarily the same in another basin, ie., spring/summer became wetter for Libby and drier at Dworshak

RMJOC

Climate Change Flood Risk Curves For Libby and Dworshak Reservoirs





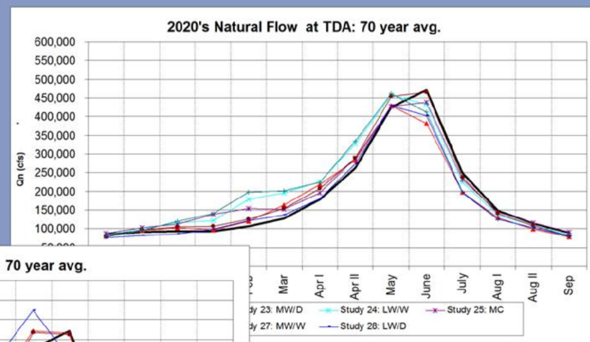
19

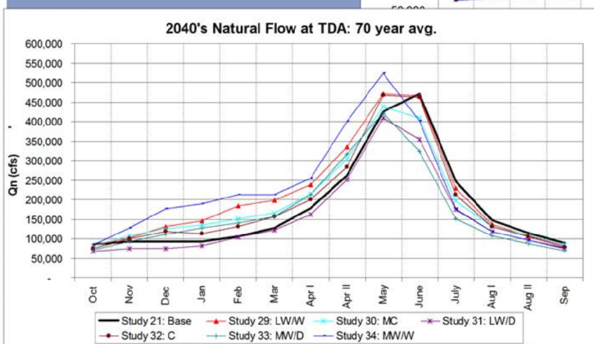
Model Input: Natural Streamflows at The Dalles for 2020's & 2040's

RMJOC

Climate Change scenarios result in higher natural streamflows in the winter to spring period…

and lower streamflows in the summer, generally speaking

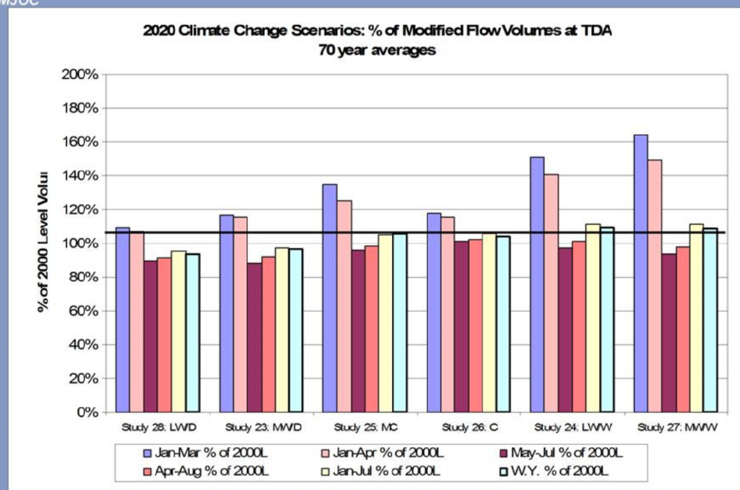




RMJOC

Model Input: Shape of Runoff for 2020's

Note that the 2040's have similar shaping characteristics



2000L Base Case Volumes @ TDA

Period	Vol (MAF)
Jan-Mar	19.5
Jan-Apr	32.5
May-July	69.4
Apr-Aug	90.5
Jan-July	101.9
Oct-Sep	131.7

Note that the Jan-April period is higher than current levels, the May-July period is lower (earlier runoff)

McNary Discharge Comparisons to Base Case

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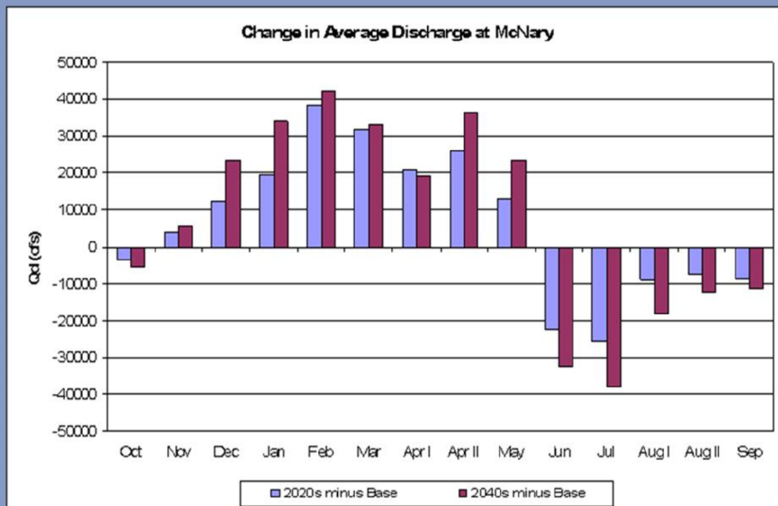

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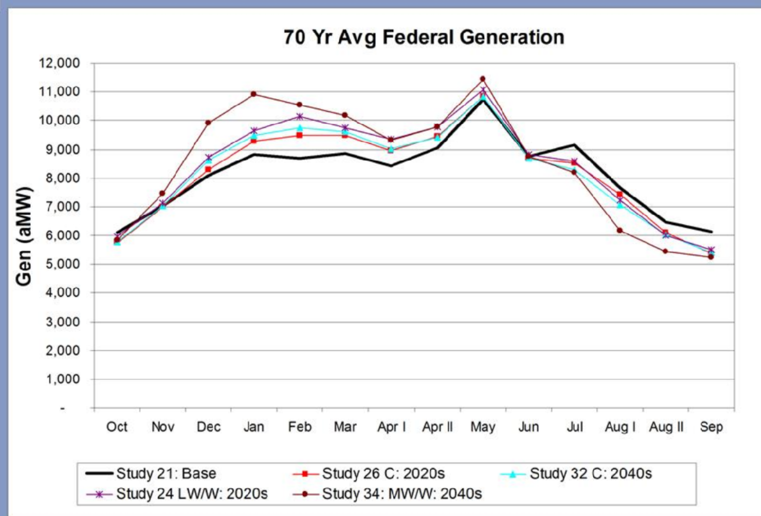
Federal Generation Comparisons for Two Central and Two Wet Scenarios



All four scenarios were modeled using the same load assumptions as the Base Case (2012 load projections)

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Next Steps
Short-Term < 10 Years

It is premature to include current climate change science in current operations. It is however, the time to start the conversation and plan for the future. Proposed actions include:

- Refining daily data to enable better analysis of flood risk.
- Conduct 2010 Modified Flow analysis (to be published this fall).
- Conduct backcasts (or use peer-reviewed backcasts already conducted) of temperature, streamflow, and seasonal streamflow ratios
- Establish criteria for when “change” warrants adjustments to current operations and planning processes (e.g. adopt climate change as the base case).
- Once IPCC’s 5th datasets are available (about 2013), identify and conduct new studies to update current, downscaled climate change scenarios.
- Coordinate and share climate change information with other Federal agencies and regional stakeholders.

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Next Steps
Long-Term Planning >10 Years

- Long-term planning processes will continue to use the 70 or 80 year modified streamflow record as the base case.
- Scenario analysis using the climate change data sets will be performed to look at the range of potential outcomes and to identify risks.
- Future long-term contracts and processes need to be flexible and adaptable to include actual climate information, especially when they span several decades.
- Some examples of future long-term planning processes that should have climate change analysis include.
  - Columbia River Treaty (2014/2024)
  - Corps Flood Risk Management Studies
  - Future BiOps
  - NEPA processes that require hydro regulation studies
  - Asset Planning for Hydro Asset Strategy
  - Maintenance planning practices and guidelines
  - BPA’s Resource Program
  - Reclamation storage studies

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